2/- net

"MECHANICAL WORLD"

ELECTRICAL POCKET BOOK

1921

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by.

LIMITED

Ponders End, Middlesex

The "Mechanical World" ELECTRICAL POCKET BOOK 1921

A COLLECTION OF ELECTRICAL ENGINEERING NOTES, RULES, TABLES AND DATA

MANCHESTER
EMMOTT & COMPANY, LIMITED
"MECHANICAL WORLD" OFFICE, 65 KING STREET
LONDON: 20 BEDFORD STREET, W.C. 2

JAPAN
THE MARUZEN-KABUSHIKI-KAISHA, TOKYO, OSAKA AND KYOTO

AUSTRALIA
E. W. COLE, MELBOURNE, SYDNEY AND ADELAIDE

PREFACE.

AMONG the important improvements made in the present issue of this popular reference book, the first place is taken by the lengthy section on Motor Starters and Controllers. The previous matter on Motor Starters has been rewritten, and the general treatment extended very considerably. The section on Transmission Conductors and Cables has been revised and a new table of Maximum Currents introduced. The matter on Wiring Systems and Methods has also been rewritten and extended. Substantial additions have been made to the section on Electric Heating and Cooking, while the matter on Electric Lifts has been rewritten. A list of Principal Abbreviations has also been included. Other revisions have been effected and a number of new illustrations introduced.

Readers desiring information on mechanical means of transmitting power, steam-engines and boilers, gas and oil engines, etc., are referred to the "MECHANICAL WORLD YEAR BOOK" for 1921, in which many new features have been introduced.

We shall be very pleased to consider practical contributions for future issues of this work, which, if accepted, will be paid for at a liberal rate. These, together with any hints or suggestions with which readers care to favour us, should be submitted not later than the *end of May*, in order to receive consideration for the following issue.

CALENDAR FOR 1921.

JANUARY

S.		2	9	16	23	30
M.		3	10	17	24	31
Tu.		4	11	18	25	...
W.		5	12	19	26	...
Th.		6	13	20	27	...
F.		7	14	21	28	...
Sa.	1	8	15	22	29	...

FEBRUARY

S.		6	13	20	27
M.		7	14	21	28
Tu.	1	8	15	22	...
W.	2	9	16	23	...
Th.	3	10	17	24	...
F.	4	11	18	25	...
Sa.	5	12	19	26	...

MARCH

S.		6	13	20	27
M.		7	14	21	28
Tu.	1	8	15	22	29
W.	2	9	16	23	30
Th.	3	10	17	24	31
F.	4	11	18	25	...
Sa.	5	12	19	26	...

APRIL

S.		3	10	17	24
M.		4	11	18	25
Tu.		5	12	19	26
W.		6	13	20	27
Th.		7	14	21	28
F.	1	8	15	22	29
Sa.	2	9	16	23	30

MAY

S.	1	8	15	22	29
M.	2	9	16	23	30
Tu.	3	10	17	24	31
W.	4	11	18	25	...
Th.	5	12	19	26	...
F.	6	13	20	27	...
Sa.	7	14	21	28	...

JUNE

S.		5	12	19	26
M.		6	13	20	27
Tu.		7	14	21	28
W.	1	8	15	22	29
Th.	2	9	16	23	30
F.	3	10	17	24	...
Sa.	4	11	18	25	...

JULY

S.		3	10	17	24	31
M.		4	11	18	25	...
Tu.		5	12	19	26	...
W.		6	13	20	27	...
Th.		7	14	21	28	...
F.	1	8	15	22	29	...
Sa.	2	9	16	23	30	...

AUGUST

S.		7	14	21	28
M.	1	8	15	22	29
Tu.	2	9	16	23	30
W.	3	10	17	24	31
Th.	4	11	18	25	...
F.	5	12	19	26	...
Sa.	6	13	20	27	...

SEPTEMBER

S.		4	11	18	25
M.		5	12	19	26
Tu.		6	13	20	27
W.		7	14	21	28
Th.	1	8	15	22	29
F.	2	9	16	23	30
Sa.	3	10	17	24	...

OCTOBER

S.		2	9	16	23	30
M.		3	10	17	24	31
Tu.		4	11	18	25	...
W.		5	12	19	26	...
Th.		6	13	20	27	...
F.		7	14	21	28	...
Sa.	1	8	15	22	29	...

NOVEMBER

S.		6	13	20	27
M.		7	14	21	28
Tu.	1	8	15	22	29
W.	2	9	16	23	30
Th.	3	10	17	24	...
F.	4	11	18	25	...
Sa.	5	12	19	26	...

DECEMBER

S.		4	11	18	25
M.		5	12	19	26
Tu.		6	13	20	27
W.		7	14	21	28
Th.	1	8	15	22	29
F.	2	9	16	23	30
Sa.	3	10	17	24	31

BANK HOLIDAYS.

Easter Monday, March 28.
Whit Monday, May 16.

August 1.
Christmas, December 26.

POST OFFICE REGULATIONS.*

INLAND LETTERS.—Not exceeding 3oz., 2d.; and ½d. for each additional 1oz.

An inland letter must not exceed the dimensions of 24in. in length, 12in. in width, and 12in. in depth.

BOOK POST—INLAND PRINTED PAPER RATE.—1oz., ½d.; and 2oz., 1d. Exceeding 2oz. but not exceeding 4oz., 1½d., and so on at the rate of ½d. for every subsequent 2oz. up to 2lb.

THE REGISTRATION of any Inland letter, newspaper, or other packet, is 2d., and all letters containing coin, posted without registration, will be charged on delivery with a registration fee of 4d., in addition to the ordinary postage.

REGISTERED LETTER ENVELOPES are sold at all Post Offices, and by Rural Messengers, according to size, from 4½d. to 6d. each. These registered letter envelopes are available for forwarding Foreign registered letters as well as Inland letters.

NEWSPAPERS registered at the G.P.O. and published at intervals not exceeding seven days, 1d. for 6oz. and ½d. for every additional 6oz. up to 2lb.

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FOREIGN LETTER POSTAGE.—To countries within the Postal Union. 2½d. for the first oz. and 1½d. for each subsequent oz. To U.S.A., 2d. for the first oz. and 1d. for each succeeding oz.

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INLAND TELEGRAMS.—For twelve words or less, 1s., and one penny per word afterwards. Addresses will be charged for.

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POSTAL ORDERS issued for 6d. to 2s. 6d., 1d.; 3s. and up to 15s.. at a cost of 1½d. each; and from 15s. 6d. to 21s. at a cost of 2d. each.

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* Operative at the time of going to press.

WAGES TABLE FOR 53 HOURS PER WEEK.

Hrs.	9/-	10/-	11/-	12/-	14/-	15/-	16/-	17/-	18/-	20/-	21/-	22/-	23/-	24/-
	s. d.	s. d.	s. d.	s. d.	s. d.	s. d.	s. d.	s. d.	s. d.	s. d.	s. d.	s. d.	s. d.	s. d.
½	0 1	0 1	0 1	0 1½	0 1½	0 2	0 2	0 2	0 2	0 2½	0 2½	0 2½	0 2½	0 3
¾	0 1½	0 1½	0 2	0 2	0 2½	0 3	0 3	0 3	0 3	0 3½	0 4	0 4	0 4	0 4½
1	0 2	0 2	0 2½	0 2½	0 3	0 3½	0 3½	0 4	0 4	0 4½	0 5	0 5	0 5	0 5½
2	0 4	0 4½	0 5	0 5½	0 6	0 7	0 7	0 8	0 8	0 9	0 9½	0 10	0 10½	0 11
3	0 6	0 6½	0 7½	0 8	0 9½	0 10½	0 10½	0 11½	1 0	1 1½	1 2½	1 3	1 3½	1 4½
4	0 8	0 9	0 10	0 11	1 0½	1 1	1 2½	1 3½	1 4	1 6	1 7	1 8	1 8½	1 10
5	0 10	0 11	1 0½	1 1½	1 3½	1 5	1 6	1 7½	1 8	1 10½	2 0	2 1	2 2	2 3½
6	1 0	1 1½	1 3	1 4½	1 7	1 8½	1 9½	1 11	2 0½	2 3	2 4½	2 6	2 7½	2 9
7	1 2	1 3½	1 5½	1 7	1 10	2 0	2 1	2 3	2 4½	2 7½	2 9½	2 11	3 0½	3 2½
8	1 4	1 6	1 8	1 9½	2 1	2 3½	2 5	2 7	2 8½	3 0	3 2	3 4	3 5½	3 8
9	1 6	1 8	1 10½	2 0½	2 4½	2 7	2 8½	2 11	3 0½	3 4½	3 7	3 9	3 11	4 1
10	1 8	1 10½	2 1	2 3	2 7½	2 10	3 0	3 2½	3 4½	3 9	3 11½	4 2	4 4	4 6½
11	1 10	2 0½	2 3½	2 6	2 10½	3 1½	3 3½	3 6½	3 8½	4 1½	4 4½	4 7	4 9½	5 0
12	2 0	2 3	2 6	2 8½	3 2	3 5	3 7½	3 10½	4 1	4 6	4 9	5 0	5 3	5 5½
13	2 2½	2 5	2 8½	2 11½	3 5	3 8	3 11	4 2	4 5	4 10½	5 2	5 5	5 8	5 11
14	2 4½	2 7½	2 11	3 2	3 8	4 0	4 2½	4 6	4 9	5 3	5 6½	5 10	6 1½	6 4½
15	2 6½	2 9½	3 1½	3 4½	3 11½	4 3	4 6	4 10	5 1	5 7½	5 11½	6 3	6 6½	6 10
16	2 8½	3 0	3 4	3 7½	4 2½	4 6½	4 10	5 1½	5 5	6 0	6 4	6 8	7 0	7 3½
17	2 10½	3 2	3 6½	3 10	4 5½	4 10	5 1½	5 5½	5 9	6 4½	6 9	7 1	7 5	7 9
18	3 0½	3 4½	3 9	4 1	4 9	5 1½	5 5	5 9½	6 1½	6 9½	7 1½	7 6	7 10	8 2
19	3 2½	3 6½	3 11½	4 3½	5 0	5 5	5 8½	6 1	6 5½	7 2	7 6½	7 11	8 3½	8 7½
20	3 4½	3 9	4 2	4 6½	5 3	5 8	6 0½	6 5	6 9½	7 6½	7 11	8 4	8 8½	9 1
21	3 6½	3 11	4 4½	4 9	5 6½	5 11½	6 4	6 9	7 1½	7 11	8 4	8 9	9 1½	9 6½
22	3 8½	4 1½	4 7	4 11½	5 9½	6 3	6 7½	7 1	7 5½	8 3½	8 8½	9 2	9 7	10 0
23	3 10½	4 3½	4 9½	5 2½	6 0½	6 6½	6 11	7 4½	7 9½	8 8	9 1½	9 7	10 0	10 5½
24	4 0½	4 6	5 0	5 5	6 4	6 9½	7 3	7 8½	8 2	9 0½	9 6	10 0	10 5	10 11
25	4 2½	4 8	5 2½	5 8	6 7	7 1	7 6½	8 0½	8 6	9 5	9 11	10 5	10 10	11 4½
26	4 5	4 10½	5 5	5 10½	6 10½	7 4½	7 10	8 4	8 10	9 9½	10 3½	10 9½	11 3	11 9½
27	4 7	5 1	5 7½	6 1½	7 1½	7 8	8 1½	8 8	9 2	10 2	10 8½	11 2½	11 8	12 2½
28	4 9	5 3½	5 10	6 4	7 4½	7 11	8 5½	9 0	9 6	10 6½	11 1	11 7½	12 1½	12 8
29	4 11	5 5½	6 0½	6 7	7 8	8 2½	8 9	9 3½	9 10	10 11	11 6	12 0½	12 6½	13 1½
30	5 1	5 8	6 3	6 9½	7 11	8 6	9 0½	9 7½	10 2½	11 3½	11 10½	12 5½	12 11½	13 7
31	5 3	5 10	6 5½	7 0½	8 2	8 9½	9 4	9 11½	10 6½	11 8	12 3½	12 10½	13 5	14 0½
32	5 5	6 0½	6 8	7 3	8 5½	9 1	9 8	10 3	10 10½	12 0½	12 8	13 3½	13 10½	14 6
33	5 7	6 2½	6 10½	7 6	8 8½	9 4	9 11½	10 7	11 2½	12 5	13 1	13 8½	14 3½	14 11
34	5 9	6 5	7 1	7 8½	8 11½	9 7½	10 3	10 11	11 6½	12 9½	13 5½	14 1½	14 8½	15 4½
35	5 11	6 7	7 3½	7 11	9 3	9 11	10 6½	11 3	11 10½	13 2	13 10½	14 6½	15 2	15 10
36	6 1	6 9½	7 6	8 2	9 6	10 2½	10 10½	11 6½	12 3	13 7	14 3	14 11½	15 7	16 3½
37	6 3	6 11½	7 8½	8 4½	9 9	10 6	11 2	11 10½	12 7	13 11½	14 8	15 4½	16 0	16 9
38	6 5	7 2	7 11	8 7½	10 0½	10 9	11 5½	12 2½	12 11	14 4	15 0½	15 9½	16 5½	17 2½
39	6 7½	7 4	8 1½	8 10	10 3½	11 0½	11 9	12 6	13 3	14 8½	15 5½	16 2½	16 10½	17 8
40	6 9½	7 6½	8 4	9 1	10 6½	11 4	12 1	12 10	13 7	15 1	15 10	16 7½	17 4	18 1
41	6 11½	7 8½	8 6½	9 3½	10 10	11 7½	12 4½	13 2	13 11	15 5½	16 3	17 0½	17 9	18 6½
42	7 1½	7 11	8 9	9 6½	11 1	11 11	12 8	13 5½	14 3½	15 10	16 7½	17 5½	18 2½	19 0
43	7 3½	8 1	8 11½	9 9	11 4	12 2½	12 11½	13 9½	14 7½	16 2½	17 0½	17 10½	18 7½	19 5½
44	7 5½	8 3½	9 2	9 11½	11 7½	12 5½	13 3½	14 1½	14 11½	16 7	17 5	18 3½	19 0½	19 11
45	7 7½	8 5½	9 4½	10 2½	11 10½	12 9	13 7	14 5	15 3½	16 11½	17 10	18 8½	19 6	20 4½
46	7 9½	8 8	9 7	10 5	12 1½	13 0½	13 10½	14 9	15 7½	17 4	18 2½	19 1½	19 11	20 10
47	7 11½	8 10	9 9½	10 8	12 5	13 4	14 2	15 1	15 11½	17 8½	18 7½	19 6½	20 4	21 3½
48	8 1½	9 0½	10 0	10 10½	12 8	13 7½	14 6	15 4½	16 4	18 1	19 0	19 11½	20 9½	21 9
49	8 3½	9 2½	10 2½	11 1½	12 11	13 10½	14 9½	15 8½	16 8	18 5½	19 5	20 4½	21 2½	22 2½
50	8 5½	9 5	10 5	11 4	13 2½	14 2	15 1	16 0½	17 0	18 10	19 9½	20 9½	21 7½	22 7½
51	8 7½	9 7	10 7½	11 7	13 5½	14 5½	15 4½	16 4½	17 4	19 2½	20 2½	21 2½	22 1	23 1
52	8 10	9 9½	10 10	11 9½	13 9	14 9	15 8½	16 8½	17 8	19 7	20 7	21 7	22 6½	23 6½
53	9 0	10 0	11 0	12 0	14 0	15 0	16 0	17 0	18 0	20 0	21 0	22 0	23 0	24 0

WAGES TABLE FOR 53 HOURS PER WEEK.

Hrs.	25/-	26/-	27/-	28/-	29/-	30/-	32/-	34/-	36/-	37/-	38/-	39/-	40/-
	s. d.	s. d.	s. d.	s. d.	s. d.	s. d.	s. d.	s. d.	s. d.	s. d.	s. d.	s. d.	s. d.
½	0 3	0 3	0 3	0 3	0 3½	0 3½	0 3½	0 4	0 4	0 4¼	0 4¼	0 4½	0 4½
¾	0 4½	0 4½	0 4½	0 4½	0 5	0 5½	0 5½	0 6	0 6	0 6¼	0 6½	0 6½	0 6¾
1	0 5½	0 6	0 6	0 6	0 6½	0 7	0 7	0 7½	0 8	0 8½	0 8½	0 8¾	0 9
2	0 11	1 0	1 0	1 0½	1 1	1 1½	1 2½	1 3	1 4	1 4¾	1 5¼	1 5¾	1 6
3	1 5	1 6	1 6	1 7	1 7½	1 8½	1 9½	1 11	2 0½	2 1¼	2 1¾	2 2½	2 3¼
4	1 10½	1 11½	2 0½	2 1	2 2	2 3	2 5	2 6½	2 8½	2 9½	2 10½	2 11¼	3 0¼
5	2 4	2 5½	2 6½	2 7½	2 8½	2 10	3 0	3 2½	3 4½	3 6	3 7	3 8¼	3 9¼
6	2 10	2 11½	3 0½	3 2	3 3	3 4½	3 7½	3 10	4 1	4 2¼	4 3½	4 5	4 6¼
7	3 3½	3 5½	3 6½	3 8	3 10	3 11½	4 2½	4 5½	4 9	4 10¾	5 0¼	5 1¾	5 3½
8	3 9	3 11	4 1	4 2½	4 4½	4 6½	4 10	5 1½	5 5	5 7	5 8¾	5 10¾	6 0½
9	4 3	4 5	4 7	4 9	4 11	5 1½	5 5	5 9	6 1	6 3½	6 5½	6 7½	6 9¼
10	4 8½	4 11	5 1	5 3	5 5½	5 8	6 0½	6 5	6 9½	6 11¾	7 2	7 4¼	7 6½
11	5 2	5 5	5 7	5 9½	6 0	6 3	6 7½	7 1	7 5½	7 8¼	7 10¾	8 1¼	8 3½
12	5 8	5 11	6 1	6 4	6 6½	6 9½	7 3	7 8½	8 1½	8 4½	8 7¼	8 10	9 0¾
13	6 1½	6 4½	6 7½	6 10	7 1	7 4½	7 10	8 4½	8 10	9 1	9 3¾	9 6¾	9 9¾
14	6 7	6 10½	7 1½	7 4½	7 8	7 11	8 5½	9 0	9 6	9 9¼	10 0½	10 3½	10 6¾
15	7 1	7 4½	7 7½	7 11	8 2½	8 6	9 0½	9 8	10 2	10 5¾	10 9	11 0½	11 3¾
16	7 6½	7 10½	8 1½	8 5	8 9	9 0½	9 8	10 3½	10 10½	11 2	11 5¾	11 9¼	12 1
17	8 0	8 4½	8 8	8 11½	9 3½	9 7½	10 3	10 11	11 6½	11 10½	12 2¼	12 6	12 10
18	8 6	8 10	9 2	9 6	9 10	10 2½	10 10½	11 7	12 2½	12 6¾	12 10¾	13 3	13 7
19	8 11½	9 4	9 8	10 0	10 4½	10 9	11 5½	12 2½	12 10½	13 3¼	13 7½	13 11¾	14 4
20	9 5	9 10	10 2	10 6½	10 11	11 4	12 1	12 10½	13 7	13 11½	14 4	14 8½	15 1¼
21	9 11	10 4	10 8	11 1	11 6	11 10½	12 8	13 6	14 3	14 8	15 0¾	15 5½	15 10¼
22	10 4½	10 9½	11 2½	11 7	12 0½	12 5½	13 3½	14 1½	14 11	15 4¼	15 9¼	16 2¼	16 7¼
23	10 10	11 3½	11 8½	12 1½	12 7	13 0½	13 10½	14 9½	15 7½	16 0¾	16 6	16 11	17 4¼
24	11 4	11 9½	12 2½	12 8	13 1½	13 7	14 6	15 5	16 3½	16 9	17 2½	17 8	18 1¼
25	11 9½	12 3½	12 8½	13 2	13 8	14 2	15 1	16 1	16 11½	17 5½	17 11	18 4¾	18 10½
26	12 3	12 9	13 3	13 8½	14 2½	14 8½	15 8½	16 8½	17 8	18 1¾	18 7¾	19 1½	19 7½
27	12 8½	13 3	13 9	14 3	14 9	15 3½	16 3½	17 4	18 4	18 10½	19 4¼	19 10½	20 4½
28	13 2	13 9	14 3	14 9	15 4	15 10	16 11	18 0	19 0	19 6½	20 1	20 7¼	21 1½
29	13 8	14 3	14 9	15 3½	15 10½	16 5	17 6	18 7½	19 8½	20 3	20 9½	21 4	21 10¾
30	14 1½	14 8½	15 3½	15 10	16 5	17 0	18 1½	19 3½	20 4½	20 11¼	21 6	22 1	22 7¾
31	14 7	15 2½	15 9½	16 4	16 11½	17 7	18 8½	19 11	21 0½	21 7¾	22 2¾	22 9¾	23 4¾
32	15 1	15 8½	16 3½	16 10½	17 6	18 1½	19 4	20 6½	21 9	22 4	22 11¼	23 6½	24 1¼
33	15 6½	16 2½	16 9½	17 5	18 0½	18 8½	19 11	21 2½	22 5	23 0½	23 8	24 3½	24 10¾
34	16 0	16 8	17 4	17 11	18 7	19 3	20 6½	21 10	23 1	23 8¾	24 4½	25 0¼	25 8
35	16 6	17 2	17 1[illegible]	18 5½	19 2	19 10	21 1½	22 6	23 9½	24 5½	25 1¼	25 9	26 5
36	16 11½	17 8	18 4	19 0	19 8½	20 4½	21 9	23 1½	24 5½	25 1½	25 9¾	26 6	27 2
37	17 5	18 2	18 10	19 6	20 3	20 11½	22 4	23 9	25 1½	25 10	26 6¼	27 2¾	27 11
38	17 11	18 8	19 4	20 0½	20 9½	21 6	22 11½	24 5	25 9½	26 6¼	27 3	27 11½	28 8¼
39	18 4½	19 1½	19 10½	20 7	21 4	22 1	23 6½	25 0½	26 6	27 2¾	27 11½	28 8½	29 5¼
40	18 10	19 7½	20 4½	21 1	21 10½	22 8	24 2	25 8½	27 2	27 11	28 8¼	29 5¼	30 2¼
41	19 4	20 1½	20 10½	21 7½	22 5	23 3	24 9	26 4	27 10	28 7½	29 4¾	30 2	30 11¼
42	19 9½	20 7½	21 4½	22 2	23 0	23 9½	25 4½	26 11½	28 6½	29 3¾	30 1¼	30 10¾	31 8½
43	20 3	21 1½	21 11	22 8	23 6½	24 4½	25 11½	27 7½	29 2½	30 0¼	30 10	31 7¾	32 5½
44	20 9	21 7	22 5	23 2½	24 1	24 11	26 7	28 3	29 10½	30 8½	31 6½	32 4½	33 2½
45	21 2½	22 1	22 11	23 9	24 7½	25 6	27 2	28 11	30 6½	31 5	32 3¼	33 1¼	33 11½
46	21 8	22 7	23 5	24 3	25 2	26 0½	27 9½	29 6½	31 3	32 1½	32 11¾	33 10¼	34 8½
47	22 2	23 1	23 11	24 9½	25 8½	26 7½	28 4½	30 2	31 11	32 9½	33 8½	34 7	35 5¾
48	22 7½	23 6½	24 5½	25 4	26 3	27 2	29 0	30 10	32 7	33 6	34 5	35 3¾	36 2¾
49	23 1	24 0½	24 11½	25 10	26 10	27 9	29 7	31 5½	33 3½	34 2½	35 1½	36 0¾	36 11¾
50	23 7	24 6½	25 5½	26 4½	27 4½	28 4	30 2½	32 1	33 11½	34 10¾	35 10¼	36 9½	37 8¾
51	24 0½	25 0½	25 11½	26 11	27 11	28 10½	30 9½	32 9	34 7½	35 7¼	36 6¾	37 6¼	38 6
52	24 6	25 6	26 6	27 5½	28 5½	29 5½	31 5	33 4½	35 3½	36 3½	37 3½	38 3¼	39 3
53	25 0	26 0	27 0	28 0	29 0	30 0	32 0	34 0	36 0	37 0	38 0	39 0	40 0

WAGES TABLE FOR 53 HOURS PER WEEK.

Hrs.	41/-	42/-	43/-	44/-	45-/	46/-	47/-	48/-	49/-	50/-	51/-	52/-
	s. d.	s. d.	s. d.	s. d.	s. d.	s. d.	s. d.	s. d.	s. d.	s. d.	s. d.	s. d.
½	0 4¾	0 4¾	0 4¾	0 5	0 5	0 5¼	0 5¼	0 5½	0 5½	0 5¾	0 5¾	0 6
¾	0 7	0 7¼	0 7¼	0 7½	0 7¾	0 7¾	0 8	0 8	0 8¼	0 8½	0 8¾	0 8¾
1	0 9¼	0 9½	0 9¾	0 10	0 10¼	0 10½	0 10¾	0 10¾	0 11	0 11¼	0 11½	0 11¾
2	1 6½	1 7	1 7½	1 8	1 8½	1 8¾	1 9¼	1 9¾	1 10¼	1 10¾	1 11	1 11½
3	2 3¾	2 4½	2 5¼	2 6	2 6½	2 7¼	2 8	2 8½	2 9¼	2 10	2 10¾	2 11¼
4	3 1¼	3 2	3 3	3 3¾	3 4¾	3 5¾	3 6½	3 7½	3 8½	3 9¼	3 10¼	3 11
5	3 10½	3 11½	4 0¾	4 1¾	4 3	4 4	4 5¼	4 6¼	4 7½	4 8½	4 9¾	4 10¾
6	4 7¾	4 9	4 10½	4 11¾	5 1¼	5 2½	5 3¾	5 5¼	5 6½	5 8	5 9¼	5 10¾
7	5 5	5 6½	5 8¼	5 9¾	5 11¼	6 1	6 2½	6 4	6 5¾	6 7¼	6 8¾	6 10½
8	6 2¼	6 4	6 6	6 7¾	6 9½	6 11¼	7 1¼	7 3	7 4¾	7 6½	7 8½	7 10¼
9	6 11½	7 1½	7 3½	7 5¾	7 7¾	7 9¾	7 11¾	8 1¾	8 3¾	8 6	8 8	8 10
10	7 8¾	7 11	8 1¼	8 3½	8 6	8 8¼	8 10½	9 0¾	9 3	9 5¼	9 7½	9 9¾
11	8 6	8 8½	8 11	9 1½	9 4	9 6½	9 9	9 11½	10 2	10 4½	10 7	10 9½
12	9 3½	9 6	9 8¾	9 11½	10 2¼	10 5	10 7¾	10 10½	11 1¼	11 3¾	11 6½	11 9¼
13	10 0¾	10 3½	10 6½	10 9½	11 0½	11 3½	11 6¼	11 9¼	12 0¼	12 3¼	12 6	12 9
14	10 10	11 1¼	11 4¼	11 7½	11 10¾	12 1¾	12 5	12 8¼	12 11¼	13 2½	13 5¾	13 8¾
15	11 7¼	11 10¾	12 2	12 5½	12 8¾	13 0¼	13 3½	13 7	13 10½	14 1¾	14 5¼	14 8½
16	12 4½	12 8¼	12 11¾	13 3½	13 7	13 10¾	14 2¼	14 6	14 9½	15 1¼	15 4¾	15 8½
17	13 1¾	13 5¾	13 9½	14 1¼	14 5¼	14 9	15 1	15 4¾	15 8½	16 0½	16 4¼	16 8¼
18	13 11	14 3¼	14 7¼	14 11¼	15 3½	15 7½	15 11½	16 3½	16 7¾	16 11¾	17 3¾	17 8
19	14 8½	15 0¾	15 5	15 9¼	16 1½	16 6	16 10¼	17 2½	17 6¾	17 11	18 3½	18 7¾
20	15 5¾	15 10¼	16 2¾	16 7¼	16 11¾	17 4¼	17 8¾	18 1¼	18 6	18 10½	19 3	19 7½
21	16 3	16 7¾	17 0½	17 5¼	17 10	18 2¾	18 7½	19 0¼	19 5	19 9¾	20 2½	20 7¼
22	17 0¼	17 5¼	17 10¼	18 3¼	18 8¼	19 1¼	19 6	19 11	20 4¼	20 9	21 2	21 7
23	17 9½	18 2¾	18 8	19 1¼	19 6¼	19 11½	20 4¾	20 10	21 3¼	21 8½	22 1½	22 6¾
24	18 6¾	19 0¼	19 5¾	19 11	20 4½	20 10	21 3½	21 8¾	22 2¼	22 7¾	23 1¼	23 6½
25	19 4	19 9¾	20 3½	20 9	21 2¾	21 8½	22 2	22 7¾	23 1¼	23 7	24 0¾	24 6¼
26	20 1¼	20 7¼	21 1¼	21 7	22 1	22 6¾	23 0¾	23 6½	24 0½	24 6¼	25 0¼	25 6
27	20 10¾	21 4¾	21 10¾	22 5	22 11	23 5¼	23 11¼	24 5½	24 11½	25 5¾	25 11¾	26 6
28	21 8	22 2¼	22 8½	23 3	23 9¼	24 3½	24 10	25 4¼	25 10¾	26 5	26 11¼	27 5¾
29	22 5¼	22 11¾	23 6¼	24 1	24 7½	25 2	25 8½	26 3¼	26 9¾	27 4¼	27 10¾	28 5½
30	23 2½	23 9¼	24 4	24 10¾	25 5¾	26 0½	26 7¼	27 2	27 9	28 3½	28 10½	29 5¼
31	23 11¾	24 6¾	25 1¾	25 8¾	26 3¾	26 10¾	27 6	28 1	28 8	29 3	29 10	30 5
32	24 9	25 4¼	25 11½	26 6¾	27 2	27 9¼	28 4½	28 11¾	29 7	30 2¼	30 9½	31 4¾
33	25 6¼	26 1¾	26 9¼	27 4¾	28 0¼	28 7¾	29 3¼	29 10¾	30 6	31 1½	31 9	32 4½
34	26 3½	26 11¼	27 7	28 2¾	28 10½	29 6	30 1¾	30 9½	31 5¼	32 1	32 8½	33 4¼
35	27 1	27 8¾	28 4¾	29 0¾	29 8½	30 4½	31 0½	31 8½	32 4¼	33 0¼	33 8¼	34 4
36	27 10¼	28 6¼	29 2½	29 10¾	30 6¾	31 3	31 11	32 7¼	33 3½	33 11½	34 7¾	35 3¾
37	28 7½	29 3¾	30 0¼	30 8½	31 5	32 1¼	32 9¾	33 6	34 2½	34 10¾	35 7¼	36 3½
38	29 4¾	30 1¼	30 10	31 6½	32 3¼	32 11¾	33 8½	34 5	35 1½	35 10¼	36 6¾	37 3½
39	30 2	30 10¾	31 7¾	32 4½	33 1¼	33 10¼	34 7	35 3¾	36 0¾	36 9½	37 6¼	38 3¼
40	30 11¼	31 8½	32 5½	33 2½	33 11½	34 8½	35 5¾	36 2¾	36 11¾	37 8¾	38 6	39 3
41	31 8½	32 6	33 3¼	34 0½	34 9¾	35 7	36 4¼	37 1½	37 10¾	38 8¼	39 5½	40 2¾
42	32 6	33 3½	34 1	34 10½	35 8	36 5½	37 3	38 0½	38 10	39 7½	40 5	41 2½
43	33 3¼	34 1	34 10¾	35 8½	36 6	37 3¾	38 1½	38 11¼	39 9	40 6¾	41 4½	42 2¼
44	34 0½	34 10½	35 8½	36 6¼	37 4¼	38 2¼	39 0¼	39 10¼	40 8¼	41 6	42 4	43 2
45	34 9¾	35 8	36 6	37 4¼	38 2½	39 0¾	39 10¾	40 9	41 7¼	42 5½	43 3½	44 1¾
46	35 7	36 5½	37 3¾	38 2¼	39 0¾	39 11	40 9½	41 8	42 6¼	43 4¾	44 3¼	45 1½
47	36 4¼	37 3	38 1½	39 0¼	39 10¾	40 9½	41 8¼	42 6¾	43 5½	44 4	45 2¾	46 1¼
48	37 1½	38 0½	38 11¼	39 10¼	40 9	41 8	42 6¾	43 5¾	44 4½	45 3½	46 2¼	47 1¼
49	37 10¾	38 10	39 9	40 8¼	41 7¼	42 6¼	43 5½	44 4½	45 3½	46 2¾	47 1¾	48 1
50	38 8¼	39 7½	40 6¾	41 6	42 5½	43 4¾	44 4	45 3½	46 2¾	47 2	48 1¼	49 0¾
51	39 5½	40 5	41 4½	42 4	43 3½	44 3¼	45 2¾	46 2¼	47 1¾	48 1¼	49 1	50 0½
52	40 2¾	41 2½	42 2¼	43 2	44 1¾	45 1½	46 1¼	47 1¼	48 1	49 0¾	50 0½	51 0¼
53	41 0	42 0	43 0	44 0	45 0	46 0	47 0	48 0	49 0	50 0	51 0	52 0

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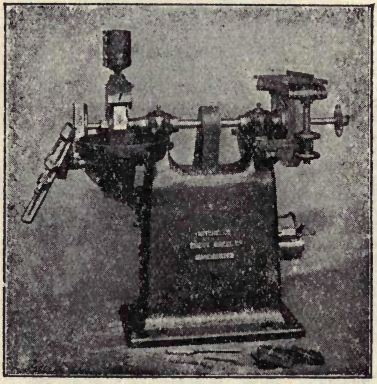
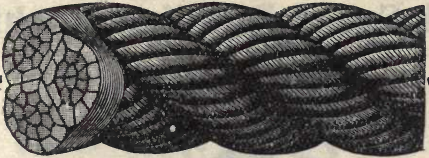
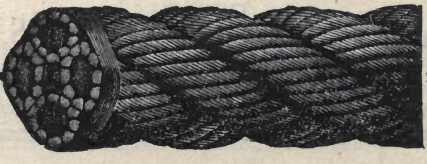
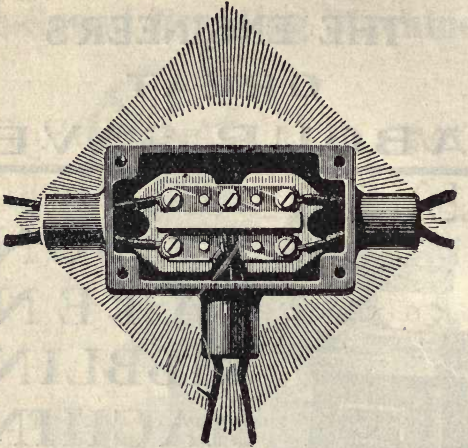








THE "MECHANICAL WORLD" ELECTRICAL POCKET BOOK.

ELECTRICAL UNITS.

The C.G.S. System.—Electrical units are all based on a system of measurement known as the Centimetre-Gram-Second, or C.G.S. system. The C.G.S. system has the following units :—

The *Centimetre* is the unit of length and is the one-hundredth part of the metre, which is the unit of length in the metric system. The *Gram* is the unit of weight, and is as the weight of a cubic centimetre of pure water at a temperature of 4° C. The *Second* is the unit of time. The *Dyne* is the unit of force, and is the force which, acting on one gram for one second, produces an acceleration of one centimetre per second per second. The *Erg* is the unit of work, and is the work done by the force of one dyne acting on a body through the distance of one centimetre. The *unit of power* is the erg per second.

The Absolute System of Electrical Units.—*The Unit of Current* is defined as that current which, when passing through a conductor 1 cm. long, bent in the arc of a circle of 1 cm. radius, produces unit force—*i. e.* 1 dyne, on a unit magnetic pole at the centre, or, in other words, produces at the centre a magnetic field of unit strength.

The Unit of Quantity.—Since the quantity passing a point in a circuit is rate of flow × time—*i. e.* current × time—the unit of quantity will be that which passes the point in one second when unit current is flowing.

The Unit of Electrical Pressure, Electromotive Force (*E.M.F.**), *or Difference of Potential*, is defined as existing between two points when 1 erg of work is necessary to cause unit quantity of electricity to flow from one point to the other, or, what comes to the same thing, when 1 erg per second is necessary to cause unit current to flow between the two points.

* For List of Abbreviations, see last page.

The Unit of Resistance.—Ohm found by experiment that the ratio Potential/Current in a conductor was constant, and this constant was named the resistance of the conductor. It follows from this that unit resistance exists when unit potential is necessary to produce unit current.

The Practical System of Electrical Units.—*The Unit of Current* (*the Ampère*).—The absolute unit of current was found to be inconveniently large, and the practical unit was fixed at one-tenth its value and called the ampère.

The Unit of Quantity (*the Coulomb*).—Since the ampère is one-tenth of the absolute unit of current, it follows that the practical unit of quantity, or, as it is called, the coulomb, is one-tenth of the absolute unit of quantity.

The commercial unit of quantity is *Ampère-Hour*, and is the quantity corresponding to one ampère flowing for one hour, hence 1 ampère hour = 3600 coulombs.

The Unit of Work (*the Joule*).—The erg, by reason of its smallness, was found to be entirely unsuited for engineering work, and the practical unit was fixed at 10,000,000 or 10^7 ergs and called the joule.

The Unit of Pressure (*the Volt*).—Since the unit of work is the product of the unit of quantity and the unit of pressure, it follows that a reduction, caused by the division of the unit of work by 10^7 and of the unit of quantity by 10, produces a practical unit of pressure equal to 10^8 absolute units. This unit is called the volt.

The Unit of Resistance (*the Ohm*).—The unit of resistance, called the ohm, now becomes by definition equal to the Volt/Ampère. Since the volt is 10^8 absolute units and the ampère is $\frac{1}{10}$ absolute unit, the ohm is 10^9 absolute units of resistance.

The Unit of Power (*the Watt*).—Just as the erg was increased to the joule, the absolute unit of power, 1 erg per second, was increased to 1 joule per second and called the watt. Now Power = Work done/Time = Quantity × Pressure/Time = Current × Pressure; therefore 1 watt is the product of 1 ampère and 1 volt. 746 watts are equivalent to 1 horse-power.

The *Kilowatt* is a larger unit of power and is equal to 1000 watts.

The Board of Trade Unit (*B.T.U.*) is the commercial unit for purposes of public supply and is measured by the product of the power and the time in hours divided by 1000. Thus 1 B.T.U. = 1000 watt-hours = 1 kilowatt-hour = 1·34 horse-power-hours.

The Unit of Capacity (*the Farad*) is the capacity possessed by a conductor when a charge of 1 coulomb raises its potential 1 volt. Since this unit is extremely large the microfarad (equal to one-millionth of a farad) is employed as the practical unit.

The Unit of Self-Induction (*the Henry*) is the induction in a circuit which gives rise to an induced potential difference of one volt in the circuit when the inducing current changes at the rate of one ampère per second.

Practical Definitions.—The three principal units may be defined as follows :—

(1) The *Ampère* is that unvarying electric current which, when passed through a solution of silver nitrate of particular strength, deposits silver at the rate of 0·001118 gram per second.

(2) The *Ohm* is the electrical resistance offered by a column of mercury, 106·3 cms. long, of a constant cross-sectional area, 14·4521 gms. in mass and at the temperature of melting ice.

(3) The *Volt* is 0·6974 (= 1000/1434) of the electrical pressure between the poles of a voltaic cell known as Clark's cell, this being at a temperature of 15° C.

The following table gives the various electrical units and their values in absolute (C.G.S.) units :—

Electrical Quantity.	Name of Unit.	Value in Absolute (C.G.S.) Units.
Current.	Ampère.	10^{-1}
Potential.	Volt.	10^{8}
Resistance.	Ohm.	10^{9}
Quantity.	Coulomb.	10^{-1}
Energy.	Joule.	10^{7}
Power.	Watt.	10^{7}
Power.	Kilowatt.	10^{10}
Capacity.	Farad.	10^{-9}
Capacity.	Micro-farad.	10^{-15}
Induction.	Henry.	10^{9}

RESISTANCE.

Law of Resistance.—The resistance of a conductor, neglecting temperature effects, is directly proportional to its length and inversely proportional to its cross-sectional area. That is $R = \rho L/A$; where R = the resistance of the conductor in ohms; L = the length of the conductor; A = the cross-sectional area of the conductor, and ρ = a constant which is different for different materials, and which is known as the *specific resistance* of the material, this being taken at a particular temperature.

The Specific Resistance of a material may therefore be defined as the resistance between the opposite faces of a cube of the material, the edge of the cube being 1 cm. (*i. e.* $L = 1$ and $A = 1$).

The specific resistance of a material varies with the temperature, and for pure metals the change is in accordance with the law $R_t = R_o(1 + at)$ where R_o = resistance at 0° C., R_t = resistance at t° C., and a = the *temperature coefficient* of the metal.

Joule's Law states that the heat produced in a circuit is directly proportional to the square of the current, to the resistance and to the time. Thus $H = KC^2Rt$ where K is the mechanical equivalent of heat and is equal to 0·24 when H is in calories, C is in ampères, R in ohms and t in seconds.

SPECIFIC RESISTANCES.

METALS.	Microhms at 0° C. Per Inch Cube.	Microhms at 0° C. Per Cm. Cube.	Ohms per Mil. Foot.	Temperature Coefficient a $R_t = R_o(1+at)$
Silver, annealed	0·578	1·468	8·80	0 004
,, hard-drawn	0·634	1·620	9·76	0·004
Copper, annealed	0·614	1·561	9·37	0·00428
,, hard-drawn	0·634	1·621	9·76	0·004
Gold, hard-drawn	0·865	2·197	13·2	0·00377
Aluminium, annealed	1·049	2·665	16·0	0·00435
Zinc	2·26	5·751	34·6	0·00406
Platinum, annealed	4·3	10·917	65·6	0·003699
Iron, annealed	3·57	9·065	54·4	0·00625
Nickel	4·85	12·323	74·0	0·00622
Tin	5·13	13·048	78·5	0·0044
Lead	8·0	20·38	122·5	0·00411
Mercury	37·0	94·07	565·0	0·00072
NON-METAL. Carbon (arc lamp).	—	4400 to 8600.	—	0·0005
ALLOYS.				
Brass	2·83	7·2	43·5	—
German silver (4 Cu + 2 Ni + 1 Zn)	8·28	21·0	126·25	0·000273
Manganin (84Cu+12Mn+4Ni)	16·56	42·0	252·5	0·000015
Platinoid (German silver + 1 or 2 per cent. tungsten)	16·4	41·7	251·0	0·0003
Platinum silver (1 Pt + 2 Ag)	12·4	31·582	190·0	0·0002
Manganese steel	26·7	68·0	409·0	0·00122
Reostene	30·0	76·468	459·0	0·0011

MECHANICAL AND ELECTRICAL UNIT EQUIVALENTS.

Units.	Equivalent Value in Other Units.
1 heat unit =	1048 watt seconds. 772ft.-lb. 0·252 calorie (kg.-d.). 108 kilogrammetres. 0·000291 kilowatt hour. 0·000388H.P. hour. 0·0000667lb. coal oxidised. 0·00087lb. water evaporated at 212° F.
1 heat unit per square foot per min. =	0·121 watt per square inch. 0·0174 kilowatt. 0·0232H.P.
1ft.-lb. =	1·36 joule. 0·1383 kilogrammetre. 0·000000377 kilowatt hour. 0·00129 heat unit. 0·0000005H.P. hour.
1lb. water evaporated at 212° F. .. =	0·33 kilowatt hour. 0·44H.P. hour. 1,148 heat units. 124,200 kilogrammetres. 1,219,000 joules. 887,800ft.-lb.
1H.P. =	746 watts. 0·746 kilowatts. 33,000ft.-lb. per minute. 550ft.-lb. per second. 2,580 heat units per hour. 43 heat units per minute. 0·71 heat unit per second. 2·25lb. water evaporated per hour at 212° F.
1H.P. hour =	0·746 kilowatt hour. 1,980,000ft.-lb. 2,580 heat units. 273,740 kilogrammetres. 2·25lb. water evaporated at 212° F. 17·2lb. water raised from 62° to 212° F.

Units.	Equivalent Value in Other Units.
1 watt =	1 joule per second. 0·00134H.P. 0·001 kilowatt. 3·44 heat units per hour. 0·73ft.-lb. per second. 0·003lb. of water evaporated per hour. 44·24ft.-lb. per minute.
1 kilowatt =	1,000 watts. 1·34H.P. 2,656,400ft.-lb. per hour. 44,240ft.-lb. per min. 737·3ft.-lb. per second. 3,440 heat units per hour. 57·3 heat units per minute. 0·955 heat units per second. 3lb. water evaporated per hour. at 212° F.
1 kilowatt hour =	1,000 watt hours. 1·34H.P. hours. 2,656,400ft.-lb. 3,600,000 joules. 3,440 heat units. 366,848 kilogrammetres. 3lb. water evaporated at 212° F. 22·9lb. water raised from 62° to 212° F.
1 kilogrammetre =	7·23ft.-lb. 0·00000366H.P. hour. 0·00000272 kilowatt hour. 0·0092 heat unit.
1 joule =	1 watt second. 0·00000278 kilowatt hour. 0·102 kilogrammetre. 0·00094 heat unit. 0·73ft.-lb.

PRIMARY CELLS.

Cell.	E.M.F.	Constituents.	Remarks.
Weston (replacing the Clark) .	1·018(5) volts at 20° C. Constant.	+ Mercury and paste of mercurous and cadmium sulphates. − 12·5 per cent. cadmium and mercury amalgan. Electrolyte — satd. cadmium sulphate.	This cell is now used as the international standard of E.M.F.
Leclanché .	1·47 volts, which rapidly falls with large current but recovers when out of use.	+ Carbon and manganese dioxide. − Zinc in a solution of ammonium chloride.	Useful for intermittent work. Deteriorates very slightly.
Bichromate	2 volts, which rapidly falls with large current but recovers when out of use.	+ Carbon, − Zinc: In a solution of bichromate of potash and sulphuric acid.	Low internal resistance.
Daniell .	1·1 volts. Constant.	+ Copper in a saturated solution of copper sulphate. − Zinc in dilute sulphuric acid.	Current remains constant for a long time and the cell deteriorates but slightly.
Bunsen .	1·9 volts. Constant.	+ Carbon in strong nitric acid. − Zinc in dilute sulphuric acid.	Deteriorates.
Grove. .	1·7 volts. Constant.	+ Platinum in strong nitric acid. − Zinc in dilute sulphuric acid.	Deteriorates.

Dry Cells are almost invariably of the Leclanché type. Types employing carbon and zinc as electrodes and the electrolytic and depolarising pastes stated are:—*Scrivanoff* (1·5v.), NH_2HgCl, NaCl, AgCl and $ZnCl_2$; *Dun* (1·8v.), KOH, $KMnO_4$; *Gassner* (1·4v.), ZnO, $CaSO_4$, NH_4Cl; *Wolff* (1·33v.), $Al_2(OH)_3$, $CaSO_4$, NH_4Cl. The *Gaiff* cell (1·02v.) employs copper and zinc in a paste of $ZnCl_2$ and AgCl. Many millions of $2\frac{1}{2}$in. × 6in. dry cells are now made per annum for use in ignition, bell and local telephone circuits, etc.; millions also of miniature dry cells ($1\frac{3}{8}$in. × $2\frac{5}{16}$in.) are built up in sets of three for use in hand or pocket flash lamps. Standard practice in the manufacture of these cells is to roll a containing vessel from 20mil. zinc plate (to form − ^{ve} electrode); line this with three layers of blotting-paper and pack the carbon rod electrode in place with a paste of the following composition

(parts by weight):—Pyrolusite (85 per cent. MnO_2), 100; ground coke, 80; artificial graphite, 20; sal ammoniac, 20; zinc chloride, 7. The MnO_2 acts as a depolariser and the $ZnCl_2$ reduces local action, and hence extends the life of the cell. If provision be not made for the escape of ammonia, the cell will burst when its container becomes thin; should the paste dry out, the activity of the cell can frequently be restored by adding water or sal ammoniac solution. A high conductivity, non-crystallising paste consists of the following parts by weight: Sal ammoniac 2; calcium acetate 2; zinc chloride 1; glycerine $\frac{1}{4}$. The powdered ingredients are mixed, covered with distilled water at 104° F., and stirred to a uniform solution which may be thickened by rye flour, kieselguhr, water glass, gelatine, starch, glass wool or sawdust. It is hardly worth while endeavouring to regenerate dry cells. Standard makes of dry cells now on the market provide about 1·5 v. and, ranging from 2 to 8 lb. in weight, have a total capacity from 140 to 200 amp.-hrs.; 100 to 155 watt-hrs.; 25 to 40 amp.-hrs./lb.; 20 to 33 watt-hrs./lb.; and 1·6 to 2·5 amp.-hrs., or 1·3 to 2·3 watt-hrs. per cub. in. On short circuit, 20 amps. or over can be taken temporarily from a 7 in. $\times$ $2\frac{1}{2}$ in. dry cell. The great practical advantages of dry cells are their cleanliness, compactness and cheapness.

If the open circuit e.m.f. of a dry cell be much below 1·5 v. the cell is defective or exhausted; average working voltage for ordinary purposes may be taken as 1 volt to allow for polarisation and increasing internal resistance. For field telephone use 1·3 v. per cell is the minimum for satisfactory working. If the short circuit current of a $7'' \times 2\frac{1}{2}''$ cell is less than 15 amps. the cell is inferior or deteriorated; but 25 amps. or higher short circuit current generally involves liability to polarisation. Dry cells should be stored in quite a cool place; deterioration is very rapid above 60° F. The current indicated by an ammeter connected momentarily across the cell terminals has recently been recognised as a better indication than the open circuit voltage of deterioration in the cell; the short circuit reading is not strictly proportional to amp.-hr. capacity, but is a better indication than the decrease in open circuit volts.

Arrangement of Cells.—If E = E.M.F. of cell; r = internal resistance of cell; R = external resistance in circuit; and C = current from cell, $C = E/(R + r)$.

Series.—If there are n cells connected in series, $C = nE/(nr + R) = E/[r + (R/n)]$.

Parallel.—If there are n cells connected in parallel, $C = E/[(r/n) + R]$ where r/n = total internal resistance.

Series Parallel (Fig. 1).—If there are s cells in each series and

p groups, $C = sE/[(rs/p) + R]$ where rs/p = total internal resistance.

Usually when R is large compared with r the cells are arranged in series, and when small, in parallel. Between these two values the mixed arrangement should be adopted. It is generally stated that max. current is obtained through a given external resistance when the cells are so arranged that their combined effective "internal" resistance equals the "external" resistance in the circuit; or, alternatively, when s is nearest $= \sqrt{(nR/r)}$. W. F. Dunton has shown, however, in his *Grouping of Electric*

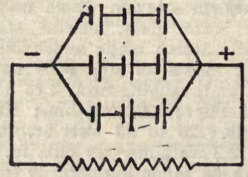


FIG. 1.

Cells, that if a be a smaller number than b, $s = a$ will give a smaller current than $s = b$, *if, and only if*, ab be smaller than nR/r. *Example:* Fourteen 2 volt, $\frac{1}{2}$ ohm cells and 0·7 ohm external resistance. The old rules would make $s = 2$ (*i. e.* cells arranged in 7 parallel groups, each of 2 cells in series); the current would then be 4·75 amps. Dunton's rule makes $s = 7$ (since $a = 2$, $b = 7$ and $ab = 14$, which is less than $14 \times 0{\cdot}7/0{\cdot}5$), and this arrangement yields over 5·7 ampères.

ELECTROLYSIS.

The Laws of Electrolysis :—

1. The amount of an electrolyte decomposed is proportional to the quantity of electricity which passes through it.

2. The amount of each element deposited by unit quantity of electricity is a definite and constant quantity which is termed the *electro-chemical equivalent* of the element deposited.

3. If the same quantity of electricity be passed through different electrolytes, the weights of the separated elements will be proportional to their chemical equivalents. Hence $W = C \epsilon t$; where W = weight in grams deposited by current of C ampères in t seconds, and ϵ is the electro-chemical equivalent which may be defined as the weight in grams deposited by 1 coulomb of electricity.

Element.	Electro-chemical Equivalent.	Element.	Electro-chemical Equivalent.
Aluminium . .	0·0000936	Silver . . .	0·0011181
Copper (cupric) .	0·0003281	Tin (stannous) .	0·0006116
Iron (ferrous) . .	0·0002902	Zinc . . .	0·0003370
Lead . . .	0·0010716	Gold . . .	0·0006791
Mercury (mercuric)	0·0010374	Hydrogen . .	0·0000104
Nickel . . .	0·0003043	Oxygen . .	0·0000823
Sodium . . .	0·0002388	Nitrogen . .	0·0000485

MAGNETIC MATERIALS AND CIRCUITS..

The only magnetic materials used in ordinary practice are iron, steel, or alloys in which iron is the predominant ingredient. It is necessary to distinguish between the magnetic properties desirable in steel to be used for permanent magnets, and those of material to be used for electromagnets, including therein the cores and yokes of transformers, dynamos, motors, etc.

Permanent Magnets.—The essential qualities of a good steel for permanent magnets are: Great hysteresis, high retentivity and coercive force, permanence and hardness (*see also* Fig. 3 and notes thereon). Tungsten- and chrome tungsten-steels make the best permanent magnets, but the physical condition of the metal is at least as important as its chemical composition in determining the intensity and permanence of magnetisation and (in the case of instrument-magnets of complex form) in determining the permanence of form and freedom from cracking. Proper hardening and heat treatment are essential, and temperature must be controlled very accurately. An excellent steel for permanent magnets is: C 0·62; W 5·7; Si 0·09; Mn 0·55 per cent.

Electro-Magnets.—The desiderata in iron to be used for the laminated cores of armatures, transformers, etc., are: High permeability, making possible light and cheap apparatus, and generally accompanied by low hysteresis; high ohmic resistance, favouring low eddy current loss; high mechanical strength, particularly in material to be used in high speed machinery. Annealing at about 1830° F., followed by slow cooling, eliminates internal strains and also restores the magnetically desirable large crystalline structure which is more or less destroyed by mechanical working.

Modern Magnetic Alloys for Dynamos, etc.—Swedish charcoal iron was formerly the standard of magnetic excellence. Hadfield found that small additions of Si or Al improved magnetic qualities. Since 1910 the potentialities of electrolytic iron have become apparent. Yet more recently it has been found that thermal treatment *in vacuo* improves enormously the magnetic

qualities of electrolytic iron which is *not*, and of commercial iron which *is* available in industrial quantities. The magnetic losses in iron so treated are reduced to about one-fifth of those in the best iron otherwise obtainable. Even a fractional percentage reduction in iron loss means a large annual saving in modern apparatus rated at thousands or tens of thousands of kilowatts. Table A gives instructive average data concerning magnetic properties.

TABLE A.—MAGNETIC PROPERTIES.

A, Swedish charcoal iron, annealed; B, 4 per cent. Si steel; C, Standard transformer steel; D, Fe_2Co, annealed; E, Pure iron, melted *in vacuo* and annealed.

	A	B	C	D	E
Max. permeability at B (gauss)	4,850 6,500	3,400 4,000	3,850 7,000	13,200–8,800 8,000	22,800–24,300 10,000–8,500
Hysteresis loss [1]	2·5–4·5	2·3–3·0	3·3–5·9	1·5–4·4	0·8–1·7
Coercive force [2]	0·88–0·95	0·88	1·2–1·33	0·48–1·0	0·33–0·22
Remanent magnetism [3] . .	6·9–8·0	5·4	7·7–9·9	9·1–12·3	9·3–14·0

[1] In 1000 ergs/cc./cycle, with B_{max} = 10,000 to 15,000 gauss.
[2] Gilberts/cm., with B_{max} = 10,000 to 15,000 gauss.
[3] In 1000 gauss, with B_{max} = 10,000 to 15,000 gauss.

Effect of Various Ingredients.—*Carbon* is magnetically injurious in dynamo steels, etc., but least so when in the form of graphite. It is difficult to eliminate; the most effective way of reducing it to graphitic form is by adding Si. *Sulphur and Phosphorus* should be avoided on mechanical grounds; more than 0·03% is unfavourable magnetically; the effect of smaller proportions is uncertain. *Aluminium.*—Up to 0·1%, the effect is favourable. *Boron* has a favourable effect in so far as it reduces iron oxide, but is detrimental in combination with iron; the percentage should not exceed 0·05%. *Cobalt* yields a definite alloy corresponding to the formula Fe_2Co, and having excellent magnetic properties. The tensile strength is twice as great (unannealed) and equal (annealed) to that of pure iron, but the alloy is brittle unless other ingredients be added. The alloy has high saturation density, high permeability at intense fields and low hysteresis loss. *Silicon* yields most useful magnetic alloys, its effect in reducing hysteresis and increasing permeability increasing with the percentage of Si. About 2% is the minimum for direct effect, and about 7% represents the limit of forging. Fractional percentages of Si are useful in reducing iron oxide and in converting carbon to the graphitic form. A larger proportion of Si forms a definite alloy with the iron, the molecules of which seem to be "lubricated" by the silicon. Si added to pure electrolytic iron

yields very much better results than can be obtained from commercial iron; permeability may be twenty times greater and hysteresis only $\frac{1}{8}$ to $\frac{1}{3}$ as great in the former case. The vacuum furnace process yields a low-Si steel, hard, ductile and of low electrical resistance; and a high-Si alloy, hard, strong and of high electrical resistance. Both alloys have high permeability and low hysteresis loss; the 0·15% Si alloy is suitable for dynamos, and the 3·4% Si alloy for transformers. The special merits of 3% to 4% Si alloys are their low hysteresis loss and high resistance, giving low eddy losses. The well-known silicon-steel *stalloy* consists of: Fe 96·2; Si 3·4; Mn 0·32; S 0·04; C 0·03; P 0·01%. Marenine suggests the following limits for a magnetic alloy: C, not more than 0·08 to 0·1; Mn, 0·1 to 0·3; Al, not over 0·1; S and P, traces only; Ni and Cu, less than 0·05; Co, large proportions seem desirable; Si, 0·5 to 0·7 for dynamos, and 3·5 to 4·5 for transformers.

Electrolytic Iron.—The merits of this material in electromagnetic service probably rest on its high degree of purity and freedom of molecular motion; it is not yet available in industrial quantities. It is claimed that electrolytic iron gives 33 to 40% better utilisation of weight in transformers; 50% or greater gain in power from a.c. motors for equal size and temperature; and 16% saving in weight of iron in d.c. motors. **Vacuum Treatment.**—Yensen prepared the best electromagnetic material yet obtained by crushing electrolytic iron, subjecting it to chemical purification, drying it *in vacuo*, and finally melting it *in vacuo* in a magnesia crucible. The product obtained has less than 0·01% each of C and Si. Steel of the highest purity commercially obtainable has its permeability increased two or three times, and its hysteresis loss reduced by melting *in vacuo*, annealing at 2010° F. and cooling slowly (86° F/hr.). The chemical composition is unaffected, but the crystals are made much larger, and tiny blowholes caused by occluded gases are eliminated. Vacuum furnaces suitable for use on an industrial scale are not yet available.

Magnetic Circuits.—The "lines of force" of a permanent magnet are assumed to radiate from the N. pole and re-enter the magnet at the S. pole, the magnetic circuit or complete path traversed by the flux being completed by the magnet itself. Wherever we have to deal with magnetic field a magnetic circuit can be traced and, granted the necessary basic data, magnetomotive force (M.M.F.), reluctance and magnetic flux can be corelated in the same way as E.M.F., resistance and current flow in an electric circuit. Where an air gap is introduced at one or more points between iron sections of a magnetic circuit, there is more or less stray field. The magnetic circuit is still complete, but some of the flux does not pass through the working section of

the air gap. The simplest magnetic circuit consists of a steel ring magnetised in the direction of its mean circumference; there is no stray field from such a circuit. If the ring be wound uniformly with a coil of wire traversed by I amps., the magnetising force along the axis of the coil is $H = 4\pi IS/10l$ lines per sq. cm., where S = number of turns, and l = mean length (cms.) of the coil. With a non-magnetic core, the field within the coil would be H lines per sq. cm. and the total flux $N_a = H \times A$, where A = cross section of coil (sq. cms.). In a core of iron, steel or other magnetic material, the magnetising force H produces a field of B lines per sq. cm. B is known as the *induction* or *flux density* in the material; it is many times greater than H, and the ratio of B to H is known as the *permeability* (μ) of the material. Thus μ (permeability) = B (flux density)/H (magnetising force) and $B = \mu H$.

Permeability is the *magnetic conductivity* or *permeance* of iron relative to air, the permeability of which is taken as unity. The permeability of iron is reduced by air or gas inclusions, which also weaken it mechanically. Permeability varies with B, the values of the latter with reference to magnetising force being shown in Fig. 2, where, however, the magnetising force is expressed in terms of the ampère-turns (IS) per inch length of magnetising coil (from the relation $H = 4\pi IS/10l$). From corresponding values of B and H, as given by these curves, the respective values of μ may be calculated. The B-H curve of a particular iron enables the designer to determine the magnetising force (*i. e.* the ampère-turns) needed to produce the desired flux destiny B.

In a closed ring of iron or steel the total flux is given by $N_i = BA = H\mu A = (4\pi IS/10) / (l/\mu A)$. From its analogy to the formula for current flow in an electric circuit, this equation may be called the Ohm's Law of the magnetic circuit. The magnetomotive force (M.M.F.) $= 4\pi IS/10$; and the magnetic resistance or *reluctance* $= l/\mu A$. Magnetic flux = M.M.F./Reluctance (*cf.* Current = E.M.F./Resistance).

The magnetic circuits of dynamos and motors include air gaps; and those of transformers generally include joints, the effect of which may be reduced to that of an equivalent air gap. If a slot of (circumferential) length l_a be cut in the wire-wound ring of iron previously mentioned, leaving a mean circumferential length of iron l_i, the flux in the air gap is given by: $N = (4\pi IS/10) / [(l_i/\mu_i A_i) + (l_a/\mu_a A_a)]$, where μ_i, A_i refer to the iron and μ_a, A_a to the air portion of the magnetic circuit.

There are a number of distinct magnetic circuits in a multipolar generator or motor. Half the flux from each north pole goes to the south poles on either side of it. From the face of the north pole, flux crosses the air gap, passes through the armature

teeth to the main body of the armature core, through which it travels circumferentially to a point under the neighbouring south pole; there the flux passes outwards through the armature teeth and air gap to the south pole core, through the latter to the yoke, and circumferentially through the yoke to the north pole. Magneto-motive force is applied to the magnetic flux at two points in the circuit, by the windings on the north and south pole cores. Each pole core forms part of two magnetic circuits, but the total number of magnetic circuits is equal to the number of poles. In order to find the ampère-turns required to overcome the total reluctance of the component parts of the magnetic circuit, the preceding formula is written in the form : $IS = 0{\cdot}8\ N\ [(l_g/\mu_g A_g) + (l_t/\mu_t A_t) + (l_a/\mu_a A_a) + v(l_p/\mu_p A_p) + v(l_y/\mu_y A_y)]$; where v is the *dispersion coefficient*, allowing for the leakage flux, which does not enter the armature; and N is the flux traversing the armature. Table B gives average values for flux density allowed in modern dynamos and motors.

TABLE B.—FLUX DENSITIES.

	Lines per sq. in.	Lines per sq. cm.
Magnetic Yoke (Cast Iron) . . .	30,000 to 45,000	4,650 to 7,000
,, ,, (Cast Steel) . . .	45,000 ,, 90,000	7,000 ,, 14,000
,, Cores (Mild Steel) . . .	80,000 ,, 120,000	12,400 ,, 18,600
,, Pole-face (Soft Iron) . .	60,000 ,, 60,000	7,800 ,, 9,300
Air-gap (500 kw.)	60,000	9,300
,, (smaller capacities) . . .	50,000 to 60,000	7,800 to 9,300
,, (5 H.P. Motors)	45,000	7,000
,, (1 H.P. Motors)	30,000	4,650
Armature Core (Steel Stampings) .	60,000 to 70,000	9,300 to 11,000
Armature Teeth (Steel Stampings) .	130,000 ,, 135,000	20,000 ,, 21,000

Hysteresis.—If a magnetic substance be subjected to a gradually increasing magnetising force until the flux density B approaches the saturation point, and the magnetising force be then reduced gradually, the returning B-H curve does not coincide with the ascending curve, but lies above it, as shown by Fig. 3, so that there is a considerable amount of *residual magnetism* OA when H is zero. A certain amount of reversed or negative magnetising force is needed to demagnetise the sample; this force is represented by OC Fig. 3, and is known as the *coercive force* of the material. The B-H curve of the material for a complete cycle of positive and negative magnetisation forms a closed loop. The induced magnetism *lags* behind the magnetising force, the phenomenon being termed *magnetic hysteresis*. The area of the loop is a measure of the work done in magnetising the material through a complete cycle. The energy thus expended per cc. per cycle = Area of loop/4π, due attention being paid to the units and scale used in constructing the loop. Steinmetz gives

the following formula for *hysteresis loss:* Hysteresis loss = $V(\eta f B_{max}^{1 \cdot 6} \times 10^{-7})$ watts; where V = volume of sample (ccs.), f = frequency or cycles of magnetisation per second, B_{max} = max. flux density (gauss) and η = a coefficient of molecular friction having the following values: Transformer silicon-steel 0·001; armature stampings 0·0012 to 0·0015; good sheet iron 0·002 to 0·005; ordinary sheet iron 0·004; soft cast steel 0·012; cast iron 0·016. The hysteresis loss in ergs per cycle per cc. for various dynamo irons and steels is: Swedish charcoal iron 8,400; Krupp dynamo steel 11,100; dynamo steel 13,500; soft steel 14,700; wrought iron 20,000. As already noted, silicon reduces the hysteresis loss of steel to which it is added. Fig. 4 shows the hysteresis loss in the best-known silicon steels—*stalloy* and *lohys*

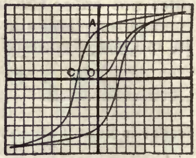


FIG. 3.

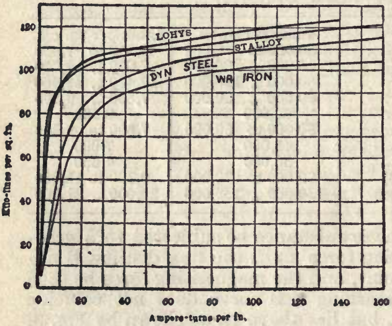


FIG. 2.

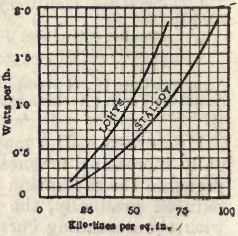


FIG. 4.

—at 50 cycles per sec. for various values of flux density, and in sheets 0·02 in. thick. Hysteresis loss decreases with temperature rise for constant H, but increases for constant B.

Eddy Currents.—When masses of iron are subjected to alternating magnetisation, an e.m.f. is set up in the material by electromagnetic induction. The *eddy currents* which then flow dissipate themselves in the form of heat and constitute another source of loss. A useful formula is: Eddy current loss = $kV(ftB_{max})^2 \times 10^{-16}$ watts; where V = volume of iron (ccs.); f = cycles per sec.; t = thickness of sheet (mils); B is in gauss; and k averages 0·42 for Si steel and 1·42 for ordinary electrical steel.

This loss is reduced by using laminated cores built up from thin sheets of iron insulated from one another by thin sheets of paper or varnish. Eddy losses vary with the resistance of the sheets which varies with temperature, depends principally on chemical composition and varies little with heat treatment. At frequencies over 100 cycles/sec. the effective resistance of sheets is increased appreciably by skin effect, hence the loss increases less rapidly than f^2. Formulæ for eddy loss assume sine voltage; if the voltage form-factor $= m$, multiply eddy loss by $(m/1{\cdot}11)^2$.

Permeability and Frequency.—There is an *apparent* decrease in permeability (μ) of iron at high frequencies due to eddy currents (which vary with f^2) confining the magnetically active portion of the iron to a thin surface layer. The true μ is practically the same at 10^6 cycles/sec. as in a constant field; at higher frequencies μ decreases to unity at 10^{10} cycles/sec.

Ageing.—After a time the magnetic losses in iron generally increase due to changes in the crystalline structure of the metal, favoured by high working temperature and depending on the chemical composition of the metal. Ferrosilicon and electrolytic iron have a stable structure little subject to ageing.

Field Magnet Windings.—The following data will be found useful in designing field coils. 1 cc. of pure copper weighs 8·9 grms.; 1 c. ft. weighs 555 lb.; 1 c. in. weighs 0·3213 lb.

Resistance of Copper.	At 15° C. (59° F.)	At 30° C. (86° F.)	At 60° C. (140° F.)
	Microhms.	Microhms.	Microhms.
Resistance of 1 in. cube . .	0·66639	0·70694	0·788
Resistance of 1 cm. cube . .	1·69259	1·79559	2·004
Resistance of 1 mil-foot . .	10·1812 ohms.	10·8 ohms.	12·05 ohms.

1 mil-foot of wire is 1 ft. in length, and 1 mil (0·001 in.) in diameter. The area of a circle in *circular mils* $= d^2$, where $d =$ diam. in mils.

At 60° C. (140° F.) the resistance of an inch cube of copper = 0·788 microhm, hence the resistance *per inch length* of a copper wire d mils in diameter $= 0{\cdot}788/\text{area} \times 10^6 = 0{\cdot}788/[(\pi d^2/4 \times 10^6) \times 10^6] = 1/d^2$ ohms very nearly.

Design of Shunt Field Coil.—The following formulæ are useful and sufficiently accurate for most practical purposes. Two cases may be noticed: (1) Where the size of wire is known or fixed in advance. (2) Where the ampère-turns is fixed and the size of wire is to be found. *Case* 1.—Let $d_1 =$ overall diam. of the wire (in.); $a =$ cross-sectional area of winding space (sq. in.); $l =$ mean length of turn (in.) $= \pi(D_1 + D_2)/2$, for a circular coil, where D_1, $D_2 =$ internal and external diams. of the coil (in.);

V = volts applied to the coil; and r = resistance per ft. of wire (ohms). Total number of turns = a/d_1^2. Total length of wire in coil = α al feet. Resistance at 60° F. = β al ohms. Field current = $\gamma V/al$ amps. Ampère-turns in winding = $\delta V/l$. In these formulæ α, β, γ and δ are constants for each size of wire; $\alpha = 1/12d_1^2$; $\beta = r/12d_1^2$; $\gamma = 12d_1^2/r$; $\delta = 12/r$. Values for the various factors are given in Table C.

TABLE C.—DATA FOR SHUNT FIELD COIL DESIGN, USING D.C.C. WIRE.

Size of Wire S.W.G.	d in.	d_1 in.	r ohms.	α	β	γ	δ
10	·128	·142	·000635	4·13	·00262	382	18,900
12	·104	·118	·000962	6·00	·00578	174	12,450
14	·080	·094	·00163	9·44	·0154	65	7,380
16	·064	·076	·002541	14·4	·0366	27·4	4,730
18	·048	·058	·00452	24·6	·112	8·94	2,650
20	·036	·046	·00803	39·1	·315	3·18	1,490
22	·028	·038	·01327	57·5	·763	1·31	906
24	·022	·032	·0215	81·2	1·75	0·572	558
26	·018	·028	·0321	106·5	3·42	0·292	373
28	·0148	·0248	·0475	135·5	6·4	0·156	253
30	·0124	·0224	·0677	166	11·2	0·0892	178

Case II.—Use the same symbols as before, and in addition let: I = field current (amps.); R = resistance of whole coil (ohms.); d = diam. of bare wire (in.); σ = resistance per inch cube; L = total length of winding (in.); S = number of turns. $I = V/R = V\pi d^2/4\sigma L$, so that $IL = V\pi d^2/4\sigma$. Substituting $L = Sl$, and using the value of σ for 60° C., we have: $d = \sqrt{\{3{\cdot}15(IS)l/\pi V10^6\}}$ for inch units. Alternatively, $d = \sqrt{\{8(IS)l/\pi V10^6\}}$ for cm. units *or* $d = \sqrt{\{12(IS)l/V\}}$ for mil-foot units, l then being expressed in feet.

The following table is useful in designing magnet cores and the windings for same—

Shape of Magnet Cores.	Circumference for Unit Area.	Relative Circumference (Circle = 1).
Circle	3·545	1·00
Square	4·000	1·13
Rectangle—1 : 2	4·243	1·20
,, 1 : 3	4·620	1·30
Ellipse—1 : 2	3·870	1·09
,, 1 : 3	4·350	1·28
Oval—1 square flanked by 2 semicircles	3·85	1·08
,, 2 squares ,, ,, ,,	4·28	1·21
2 circles side by side	4·10	1·13

Lifting-Magnets. — Electro-magnets are now used in large numbers to handle iron and steel blocks, rails, sheets, small parts and turnings. They cannot be used for hot ingots, etc., since iron becomes non-magnetic at about 1350° F. (750° C.). Large quantities of material can be handled quickly, safely and economically if the magnet be well designed and built. The smallest air gap (due to irregular or dirty surface) seriously reduces magnetic pull, hence lifting capacity for scrap and turnings is less than for heavy blocks. Specially designed magnets and polepieces should be used where large quantities of pieces of one pattern have to be handled. Magnet windings must be well cooled, yet protected against mechanical injury. Different makes of magnet vary in performance, and the capacity of any magnet varies with circumstances. Table D affords a general guide.

TABLE D.—TYPICAL DATA FOR LIFTING-ELECTROMAGNETS.

Magnet.		Approximate Carrying Power (lb.) for—		
Consumption Kws.	Net Weight. lb.	Pig iron, forging waste, turnings or shot.	Small Pieces.	Heavy Blocks.
1	450	110–175	300–400	4,000
2	1,300	300–550	650–1,500	11,000
3	2,000	450–850	1,000–2,000	18,000
5	3,100	650–1,200	1 600–2,800	32,000
7·5	4,400	1,000–1,500	2,200–3,300	50,000

CONTINUOUS CURRENT DYNAMOS AND MOTORS.

Types of D.C. Machines.—Continuous current dynamos and motors are generally "self-excited" machines and, according as the field winding is in series with the armature (Fig. 5), in parallel or shunt with the armature (Fig. 6), or a combination of these arrangements is employed (Fig. 7), the machine is said to be *series-*, *shunt-* or *compound-wound*.

Series-wound dynamos work best as constant current machines and on circuits of constant resistance. The terminal voltage of a *shunt-wound generator* falls slightly with increasing load owing partly to armature reaction and partly to greater pressure drop in the armature. Constant terminal voltage may be maintained by use of a field rheostat. The shunt-wound machine is suitable for charging accumulators.

The Compound-wound Generator. is a combination of the series- and shunt-wound machines, being provided with both series and shunt windings, and within certain limits combines the characteristic properties of the series- and shunt-wound generators, and, if properly designed, it gives a constant terminal voltage with varying loads within the prescribed limits. It is therefore specially adapted for power work and variable loads, and when a few additional turns are added to the series windings—*i. e.* when it is *over-compounded*—it may be designed to give a constant voltage at the distant distributing centres, and so compensate for the loss of volts in the mains with increase of load. For special work, as in traction and power service, the over-compounded generator is specially adapted, and is universally used.

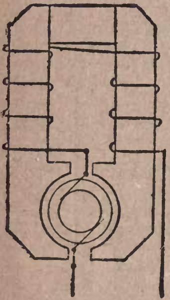


FIG. 5.

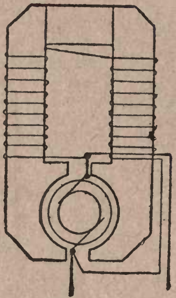


FIG. 6.

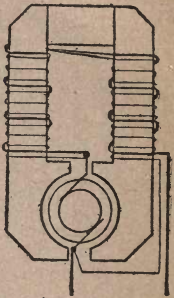


FIG. 7

Armatures.—The armature of d.c. machines may be classified (1) according to the nature of the core; thus we have—

(*a*) *Smooth-cored* armatures, in which the conductors are disposed on the outside of a smooth cylindrical laminated iron core.

(*b*) *Tooth-cored* armatures, in which the conductors are embedded in grooves, channels, or slots cut into the outer surface of the laminated core.

(2) According to the disposition of the conductors on the armature core—

(*c*) *Drum* armatures, in which the insulated conductors are wound lengthwise—*i. e.* parallel to the shaft upon the outside surface of the cylindrical core or drum, as shown in Fig. 8. Each spiral, therefore, supplies two active conductors, one nearly diametrically opposite to the other in a bipolar machine, con-

sequently there are no return conductors in the interior of the core. This type of armature is now used almost universally.

(*d*) *Ring* or *Gramme* armatures, in which the insulated conductors are wound spirally around an annular ring or hollow cylindrical core, so as to form an endless helix, tappings being taken off to the commutator segments, as shown in Fig. 9.

Drum-wound armatures are in general former wound, and are therefore cheaper than ring-wound armatures, the latter being now seldom used. Drum-wound armatures are divided into two distinct classes: (1) the *wave-wound* armature, and (2) the *lap-wound* armature. In forming the coils for drum windings the width of the coil, which is technically termed the *pitch*, *step*, or *throw* of the winding, is made nearly equal to the pole-pitch in order that the E.M.F.'s induced in the conductors may be accumulative. In the case of the wave winding the connections are such that there is a stepping forward all the time, as shown in Fig. 10. For the sake of simplicity only single conductors, not coils, are indicated, and it will be observed that the winding proceeds in a zigzag or *wavy* line around the periphery of the armature, and in order that all the conductors may be included

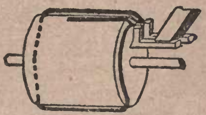


FIG. 8

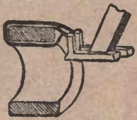


FIG. 9.

it is clear that the pitch of the winding, expressed in terms of the number of conductors, must be an *odd* number. Since the successive coils are connected in series, the wave winding is also known as the *series-* or *two-circuit* winding, and the characteristic feature of this type of winding is that only two sets of brushes are required, whatever may be the number of poles. This winding is adopted for machines giving high voltages and small currents.

With lap windings (Fig. 11) the interconnections are such that the winding progresses by forming loops, the front connections lapping backwards towards the slots from which the back connections commenced, hence the name *lap winding*. This type of winding is adopted for machines giving large currents at low pressures, and a little consideration shows that there are as many parallel branches formed by the armature circuits as there are poles.

Electromotive Force produced by an Armature.—The E.M.F. generated in a conductor rotating in a magnetic field is directly proportional to the time rate of change in the number of linkages of the flux with the conductor, the C.G.S. unit of E.M.F. being produced when the change is at the rate of one linkage per second. Let Z = total number of armature conductors connected in series; N = flux per pole ; p = number of poles; n = revolutions per second; c = number of branches of armature conductors connected in parallelism by the brushes; = 2 for wave-wound armatures; = p for lap-wound armatures.

From first principles each conductor of the armature cuts N lines of force in $(1/pn)$th of a second, consequently the average time rate of change in the number of linkages per conductor is $N/(1/pn)$ or $p\,N\,n$ per second. Now with c sets of conductors connected in parallel between the brushes, there will be Z/c conductors connected in series in each branch, therefore the E.M.F.

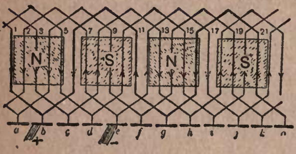


FIG. 10.

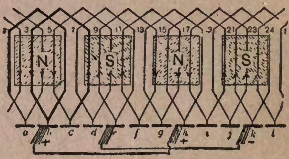


FIG. 11.

set up between the brushes will be $(Z/c)pNn$ C.G.S. units, and since there are 10^8 C.G.S. units of E.M.F. in the volt, the E.M.F. induced in the armature for a speed of n revolutions per second is given by the expression $E = (p/c)\,N\,Z\,n \times 10^{-8}$ volts.

Dimensions of the Armature.—The size of an armature core depends upon a number of factors, the chief of which are the output and the speed. As Esson suggested in 1891, a rational relationship exists between the *volume* of the armature and the output per revolution for all classes of generators, or algebraically $D^2L = K \times \text{Kilowatts}/r.p.m.$ in which D is the diameter of the armature, L is the length of the armature, and K is the *output coefficient.* E. K. Scott gives the following values of K, when D and L are expressed in inches: Largest fly-wheel dynamos, K = 30,000; Large multipolar, K = 33,000; Small multipolar, K = 55,000; Large bipolar, K = 70,000; Small bipolar, K = 140,000.

Dynamo Speeds.—For continuous-current generators the Committee on British Engineering Standards give the following values of the speeds for engines—

	Output in K.W.	Class of Engine—Revs. per Min.		
		Low Speed.	Medium Speed.	High Speed.
Very Small . .	30 to 80	125 to 127	300 to 250	625 to 525
Small . . .	100 to 250	107	250	500 to 375
Medium . . .	300 to 500	94	214	375 to 300
Large . . .	750 to 1000	83	188	250
Very Large . .	1500 to 2500	75	166	214
Extra Large . .	3000 to 5000	75	150	188

Direct-Current Motors.—The dynamo is a reversible machine; it transforms mechanical power into electrical power, and when supplied with electrical power under proper conditions it generates torque and operates as a motor, converting electrical power into mechanical power. Experiment proves that when a conductor carrying a current is disposed so that its direction is perpendicular to that of the field it is urged in a direction perpendicular to the direction of the current and to the direction of the magnetic field. As regards construction, the motor is identified with the dynamo. A back e.m.f. is set up in the armature when it rotates and generates torque, and for a constant pressure applied to the armature, constant resisting torque and constant armature resistance, the speed varies inversely as the magnetic flux N; hence the rule—

"*Weakening* the magnetic field *increases* the speed, whilst strengthening the field *decreases* the speed; also that the speed is proportional to applied voltage, and is decreased by inserting resistance in the armature circuit, as is customary when starting from rest." The usual method of obtaining speed variation is to use a rheostat in the field-magnet circuit, so that the field may be weakened or strengthened as desired.

There are three types of d.c. motors, the *series*, *shunt*, and *compound*, each of which possesses characteristic features with respect to starting torque, running torque and speed. The *series-wound machine* is used to a much greater extent as a motor than as a generator on account of its excellent starting torque, even against load, and in traction work it is used almost universally. Its speed falls off as the load is increased, and it is liable to race should its load be thrown off, owing to its then weak field.

The *shunt motor* is defective so far as starting torque is concerned, but it has a large sphere of usefulness as it is approximately a *constant speed* motor with varying load. Considerable speed variation may be obtained with rheostatic control in the

field circuit, but it is imperative that it should be started with resistance inserted in the armature circuit. (*See* section on Motor Starters.)

The *compound motor* has both series and shunt field coils. Usually these aid one another (cumulative compounding); but for special services they may oppose their effects (differential compounding). The *cumulative-compound* motor has high starting torque due to its series field, but (thanks to its shunt field) no tendency to race on light load or to slow down on heavy loads to the same extent as a series motor. These motors are useful for shaft driving and where there are heavy and sudden overloads, also in elevator work. In the latter case, the series turns are often cut out when the motor is up to speed, thus combining the advantage of high starting torque with the constant speed of a pure shunt motor at full speed. The *differential-compound* motor is a treacherous machine. It may be designed to give constant or even rising speed with load. When starting, the series field becomes operative sooner than the field of the highly inductive shunt coils, so that the machine is apt to start in the wrong direction; its subsequent reversal is a heavy mechanical strain and probably blows the fuses. If speed control is provided by variable shunt field the series field may predominate at high speed, causing the machine to stop and reverse.

EFFICIENCIES OF D.C. DYNAMOS AND MOTORS.

Though the precise values vary considerably with the quality of design and workmanship, with the quantity and quality of materials employed, and with the speed of the machine, the subjoined figures form a useful guide to the general distribution of losses in and approximate overall efficiency of shunt and series-wound d.c. dynamos and motors.

Rating.		Shunt Wound Machines.					Series Traction Motors.*				
		C²R loss (%).		Core Loss (%).	Friction (%).	Efficy. (%).	C²R loss (%).		Core Loss (%).	Friction (%).	Efficy. (%).
Kws.	H.P.	Armtr.	Field.				Armtr.	Field.			
1	1·3	4·3	5	4	6·5	80	—	—	—	—	—
5	6·7	3·8	3·6	3·1	5	85	—	—	—	—	—
10	13·4	3·7	3·0	2·8	4	87	—	—	—	—	—
20	27	3·3	2·5	2·4	3	88½	8·4	7	2·5	6·0	76
50	67	3·0	2·0	2·0	2·5	90	5·0	4·5	2·0	5·0	83
100	134	2·6	1·8	1·6	2·3	91½	3·2	3·5	2·0	5·0	86
200	269	2·4	1·7	1·5	2·2	92	2·7	3·0	1·5	4·0	89
500	670	2·0	1·6	1·4	2	93	—	—	—	—	—

* With commutating poles.

DYNAMO AND MOTOR DEFECTS.

SPARKING AT THE BRUSHES.	Brushes Faulty.		Not set diametrically opposite	A. Set correctly by counting bars or by measurement on commutator. B. To set while running (if necessary) rock till brush on one side sparks least; adjust other brushes till sparking ceases.	1
			Not at neutral points	Move rocker to and fro slowly till sparking ceases.	2
			Not trimmed properly	A. Should trim before starting. Bend back or cut off loose wire or ragged copper. If two or more brushes, remove one at a time for trimming. B. Clean copper with benzine, soda or potash; carbon with alcohol or ether; file or grind in jig and reset. *See* 1, 4, 36.	3
			Not in line	Adjust to bear evenly, squarely and in line on commutator. *See* 12A.	4
			Contact bad	A. Remove oil and grit from commutator; examine brush leads and contacts in brush boxes and on commutator. B. Adjust tension screws and spring to give light, firm, even contact.	5
	Commutator Faults.		Rough, grooved or out of round	A. Grind by fine sand paper on curved block. Polish by crocus cloth. NEVER use emery. B. If necessary take light cut at slow speed in lathe or (better) own bearings. *Note.*—$\frac{1}{16}$ to $\frac{1}{8}$in. end play in the bearings permits commutator to wear smooth and even. *See* line 29.	6
			High bars	Set down by mallet or wood block and tighten end nuts. File, grind or turn true if necessary. May cause singing. *See* line 36.	7
			Low bars	Grind or turn true to surface of low bars.	8
			Weak field	A. Break or short in field coils. Repair if external; rewind if internal. B. Windings or iron improperly designed. No remedy except rebuilding.	9
	Armature current excessive.	Generator.	Load too high. Ground and leak—line short circt. Dead short on line	A. Reduce number of lamps and load. B. Test out, locate and repair. C. Should blow fuses. Shut down, locate fault and repair. Insert new fuse.	10
		Motor.	Volts excessive. Amps. excessive on const. ct. circt. Friction. Pulley load excessive	D. Use proper current only and with proper rheostat, controller and switch. E. See that controller, etc., are suitable, with ample resistance. F. See that there is no undue friction or mechanical resistance anywhere. G. Reduce load to rated capacity or less. *See* 3B, 33 and 34.	

DYNAMO AND MOTOR DEFECTS—(*Continued*).

Sparking at the Brushes.	Armature Faults.	Short circuited coils	A. Remove copper dust, solder or other conducting material between commutator bars. B. See clamping rings are free and insulated for commutator bars. No copper dust, carbonised oil, etc. C. Test for cross connection or short circuit; rewind armature to correct. D. See brush holders are insulated. No copper or carbon dust, etc., to cause leak. *See* 1, 2, 55.	11
		Broken coils	A. Bridge break temporarily by staggering brushes (to save bad sparking). Shut down and repair soon as possible. B. Shut down if possible and repair loose or broken connection to commutator bar. C. If coil broken inside, repair temporarily by connecting to next coil across mica. Rewind soon as possible. D. Solder commutator lugs together or use "jumper" to cut out and leave open the broken coil. Do not short a good coil. *See* 11.	12
		Cross connections	Effect and treatment as for short circuit. *See* 11. Test each coil for no cross and no ground.	13
Heating of Parts.	Armature.	Overloaded	Current excessive; too many lights or too much power. *See* 10, 11, 12, 13.	14
		Short circuit	Generally dirt, metal or carbon dust between commutator bars. *See* 10, 11, 12, 13.	15
		Broken circuit	Often caused by loose or broken band. *See* 10, 11, 12, 13.	16
		Cross connection	Often due to loose coil rubbing on another or on core. *See* 10, 11, 12, 13.	17
		Moisture in coils	Dry by gentle heat (by small current sent through or generated by m/c. running slowly).	18
		Eddy currents in core	Iron hotter than coils. Core should be of thin insulated laminations. No remedy but to rebuild.	19
		Friction	Hot boxes or journals may affect armature. *See* 22, 31.	20

DYNAMO AND MOTOR DEFECTS—(*Continued*).

HEATING OF PARTS.	Field Coils.	Current excessive	Shunt	A. Reduce speed to lower terminal volts. Increase field resistance by more or finer wire or by series resistance.	21
			Series	B. Decrease field current by shunt, remove some of winding or rewind with larger wire.	
			Note	May be due to short circuit or leakage due to moisture. *See* 9, 23.	
		Eddy currents		Core hotter than coil after short run; construction faulty or current fluctuating. If latter, regulate and steady.	22
		Moisture in coils		Apparent coil resistance low; may cause short to frame. *See* 18 and 21 *note*.	23
	Bearings.	Insufficient or poor oil		A. See that plenty of good, clean mineral oil feeds. Keep it off commutator and brush holder. *See* 11. B. If necessary to complete run use cylinder oil or vaseline mixed with sulphur, white lead or potassium hydrate. Clean and put in order soon as possible.	24
		Dirt or grit in bearings		A. Wash out with oil while running; clean up and put in order. Keep oil from commutator or brushes. B. Let cool naturally if shut down. Unbuild, clean (scrape if necessary) and polish journals and bearings. See all parts free. Lubricate well.	25
		Rough journal or bearing		Smooth and polish in lathe. Rebabitt old boxes and fit new ones.	26
		Journals too tight; or shaft bent		Slacken cap bolts, put in liners and retighten till run is over. Then scrape, ream, bend, turn or grind, etc., as required. Possibly a new box or shaft will be needed.	27
		Bearings out of line		Loosen bearing bolts, line up and block till armature is in centre of pole pieces. Ream out dowel and bolt holes and fix in new position.	28
		End pressure of pulley hub or shaft collars		A. See that foundation is level and armature has free end motion. B. If no end motion, file or turn boxes or shaft shoulders to provide it. C. Line up shaft and belt; get no end thrust but free armature end play when running.	29
		Belt too tight		A. Slacken belt, reduce load if slipping occurs. Avoid vertical belts. B. Use larger pulleys, wider and longer belts with slack side on top. Flapping belts make lamps wink.	30
		Armature out of centre of pole pieces		A. Bearings may be worn and need replacing. *See* 34. B. Centre armature in polar space and adjust bearings to suit. *See* 28. C. File out polar space to give equal space all round. D. In small machines, pole may be sprung away from armature in places.	31

DYNAMO AND MOTOR DEFECTS—(*Continued*).

NOISES.	Armature or pulley out of balance		Faulty construction; should have been balanced when made. Subsequent balancing demands experience.	32
	Armature fouls pole pieces		A. Bend or press down projecting wires; secure by tie bands. B. File out pole pieces where armature strikes. *See* 28, 31.	33
	Shaft projections foul box		Bearings may be loose or worn; adjust or renew. *See* 28, 29.	34
	Loose bolt or screws		Examine daily all bolts and screws.	35
	Brushes sing or hiss		A. Apply mere trace stearic acid (adamantine) candle, vaseline or cylinder oil to commutator. B. Move brushes in holder to get firm, smooth, gentle pressure. *See* 3, 6, 7, 8, 29.	36
	Belt flaps		Use endless belt or one with neatly laced square ends.	37
	Belt slips		Tighten belt and reduce load if necessary. *See* 30.	38
	Humming armature, lugs or teeth		A. Slope end of pole piece so that armature does not pass edges all at once. B. Decrease magnetism of field or increase magnetic capacity of tooth.	39
SPEED. Runs too fast.	Engine regulation faulty		Adjust governor to regulate properly from no load to full load or get better engine.	40
	Series Motor	Too much current and runs away	A. Constant current series motor. (1) Adjust to proper current by a shunt. (2) Use regulator or governor to control field magnetism for varying load. B. Constant potential series motor. (1) Insert resistance and reduce current. (2) Use a proper regulator or controlling switch. (3) Change to automatic speed-regulating motor.	41
	Shunt Motor	Regltr. set wrongly. Current not right. Motor unsuitable	A. Adjust regulator to control motor. B. Use only current of proper voltage and with proper rheostat. C. Get better motor, one properly designed for the work.	42
	Runs too slow		43. Engine fails to regulate, *see* 40. 44. Overload, *see* 10A. 45. Armature short circuit, *see* 11. 46. Armature fouls, *see* 33. 47. Friction, *see* 10F. 48. Weak magnetic field, *see* 9.	43 to 48

DYNAMO AND MOTOR DEFECTS—(*Continued*

			Defect	Remedy	No.
MOTOR.	Stops or will not start		Overload. See 10F and G Friction. See 24, 31 and 33	Open switch, find and repair trouble. Failure to start or stopping produces no great harm in series motor but blows fuse or burns out armature of constant potential shunt m/c.	49
		Circuit open	Fuse melted or switch open Broken wire or connection Brushes not in contact Current fails	A. Open switch, find and repair trouble, replace fuse. *See* 10C. B. Open switch, find and repair trouble. *See* 12. C. Open switch and adjust. *See* 5. D. Open switch, return starter to "off." Wait for current.	50
			Short circuit in field, armature or switch	Test for and repair. Examine insulation of terminals and brush holders. Poor insulation, dirt, oil, copper, or carbon dust often cause short circuit.	51
	Runs backwards			Connections wrong. If no diagram available, reverse brush or other connections till rotation correct. Differentially compounded motor may start in wrong direction or reverse at high speed due to predominance oı series field. *See* chap. on C.C. Dynamos and Motors.	52
DYNAMO OR GENERATOR.	Reversed Residual Magnetism		Field current reversed Connections reversed Earth's magnetism Near another dynamo Brushes set wrongly	A. Magnetise correctly from another dynamo or battery. Test polarity by compass. B. If connection or windings not known, try one way and test; reverse if necessary. C. Connect as per diagram for desired rotation; see shunt and series connections correct. *See* 52. D. Shift brushes till they operate better. *See* 1, 2, 3.	53
	Weak residual magnetism			Same as 53A.	54
	Short circuit in machine			*See* 11, 51.	55
	External short circuit			Lamp socket, etc., may be shorted or grounded and prevent building up shunt and compound m/cs. Find, remedy and then close switch. *See* 51.	56
	Field coils opposed			Reverse connections of one coil and test, using compass. If necessary try 53 A, C, D.	57
	Compound opposing shunt field			Voltage decreases with increased load; m/c may be satisfactory on lighting, but not on traction. Reverse the compound leads.	57*a*
	Open circuit			Find and repair. Broken wire, *see* 12. Faulty connection, *see* 35. Brushes not in contact, *see* 5. Fuse melted or broken, *see* 50A. Switch open, *see* 50D. External circuit open—keep dynamo switch open till repairs completed.	58
	Load excessive			Reduce load to pilot lamp on shunt and incandescent m/cs; close switches slowly in succession and regulate volts. *See* 10A and 60.	59
	Field resistance too high			Bring up volts gradually with rheostat; watch pilot lamp; regulate carefully.	60

ALTERNATE CURRENT SYSTEMS.

ALTERNATING current as used for commercial purposes should be as nearly as possible a sine function of time, and may be represented graphically as in Fig. 12. Such a current is the result of an alternating E.M.F., produced by an alternator. The only essential difference between a d.c. generator and an alternator is that the latter has no commutator or other rectifying device. The instantaneous value of an alternating E.M.F. is given by the equation $e_t = E_{max} \sin 2 \pi ft = E_{max} \sin (2 \pi/T)t$; where e_t, E_{max} = instantaneous and maximum values respectively of the E.M.F.; T = periodic time (represented by $a\ c\ e$, Fig. 12); f = frequency or periodicity in cycles per sec. = 1/T; and t = the instant of time corresponding to e_t. A similar expression holds good for the instantaneous value of the current.

FIG. 13.

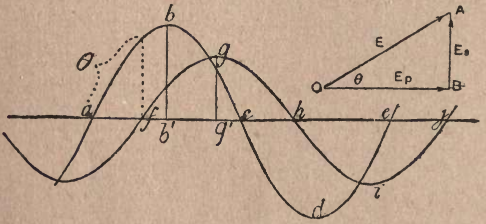


FIG. 12.

Lower frequencies are preferable for power purposes than for lighting. In this country a compromise has led to the general use of 50 cycles per sec. for both lighting and power. In the United States the usual frequencies are 25 and 60 cycles. For single phase railways 15 cycles per sec. is usual.

The maximum value of a.c. E.M.F. is important as regards the max. stress on insulation, but in general it is the *effective*, *virtual*, or *root mean square* (R.M.S.) value of pressure or current which is important, and this is given by the square root of the mean of all the squares of the instantaneous values. So long as the pressure or current is represented by a sine curve, the R.M.S. value = Max. value/$\sqrt{2}$, *i. e.* Virtual volts = 0·707 E_{max}; and Virtual amperes = 0·707 C_{max}.

An alternating current rarely attains its max. and zero values at the same instant as the E.M.F. In Fig. 12 the curve $a\ b\ c\ d\ e$ may represent an alternating E.M.F. and $f\ g\ h\ i\ j$ the resulting

current. The *difference in phase* between the two curves is represented by the distance b^1g^1 (or $a\ f$) on the zero line, and, since $a\ e$ represents 360° or 2π, the phase displacement of the current is $\theta° = (a\ f/a\ e) \times 360°$. The curves run from left to right, hence θ represents an *angle of lag* in this case.

Power-factor.—The effect of phase difference (whether lag or lead) between a.c. pressure and current is that the mean power absorbed in an a.c. circuit is less numerically than the product Volts × Amperes. Actually the expression for power in a.c circuits is $W = E\ C. \cos\theta$, in which the factor $\cos\theta$ is the *power factor*, and is the cosine of the angle of current lag or lead. The power factor is given by the ratio W/EC = True watts/Apparent watts. In the case of a balanced 3 ph. system, the power factor ($\cos\theta$) may be deduced from the "tangent formula":—$\tan\theta = \sqrt{3}[(W_1 - W_2)/(W_1 + W_2)]$, where W_1, W_2 = the two wattmeter readings in the two wattmeter method of measuring 3 ph. power. Knowing $\tan\theta$, we have $\cos\theta = 1/\sqrt{[(\tan\theta)^2 + 1]}$.

The lower the power factor, the heavier the current required to obtain a certain effective output at a given voltage, and hence the heavier the conductors required. A motor operating at 0·8 power factor requires 1/0·8 = 1·25 times as much current as is required at unity power factor. Inductive effect is less, the lower the frequency, hence lower frequency results in higher power factor in mains and appliances. *Average values of power factor*:—Lighting loads 0·95; lighting and power combined 0·7 to 0·85; power loads or transformers 0·6 to 0·8.

Ohm's Law for A.C. Circuits.—The E.M.F. E impressed on an a.c. circuit may be resolved into two components at right angles, viz. a "power E.M.F." E_p (Fig. 13) in phase with the current and equal to the ohmic drop C R; and a "wattless E.M.F." E_s in quadrature with E_p, required to neutralise the E.M.F. of self induction and equal to $2\pi f LC$, where L is the self inductance of the circuit. The angle between E and E_p is θ, the angle of lag, and we have $E^2 = E_p{}^2 + E_s{}^2 = C^2\ (R^2 + \omega^2 L^2)$, where $\omega = \pi\ f$. It follows that $C = E/\sqrt{(R^2 + \omega^2 L^2)}$ which reduces to the form $C = E/R$ if the inductance be zero. The term $\sqrt{(R^2 + \omega^2 L^2)}$ represents the *impedance* of a circuit of resistance R and inductance L.

The effect of capacity is to cause the current to *lead* on the E.M.F. and we have: $C = E/\sqrt{[R^2 + (1/\omega^2 K^2)]}$ for a circuit of resistance R ohms and capacity K farads. If the circuit contains resistance, inductance and capacity in series, $C = E/\sqrt{\{R^2 + [\omega L - (1/\omega K)]^2\}}$. Capacity reduces to a greater or less extent, the effect of inductance.

ALTERNATORS.

In small and low voltage alternators it is usual to employ a stationary field and revolving armature, but in large and high voltage machines, it is usual to rotate the field system and keep the armature stationary, thus avoiding the collection of high voltage current through rubbing contacts. In either case, no commutator is employed and the field magnets are separately excited. The relationship between the number of poles, the speed of the motor and the frequency of the current generated is expressed by the formula :—$f = \text{p.n.}$, where f = cycles per sec.; p = *pairs* of poles; and n = revs. per sec.

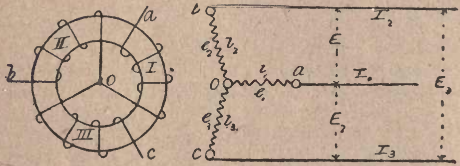


FIG. 14.

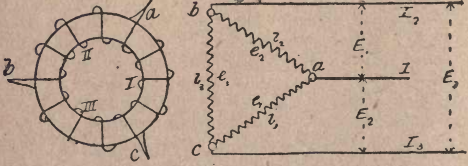


FIG. 15.

To avoid differential action between E.M.F.'s induced in individual conductors, only about 50 per cent. of the armature periphery may be used for the winding of a single phase alternator. In a two phase alternator, the vacant space between the sections of the single phase winding is used to accommodate a similar but independent winding in which is generated an E.M.F. equal to that in the first winding but displaced 90° in phase. The two phase system is a double single phase system and the

two windings are usually kept distinct, with two pairs of slip rings for connection with the external circuits.

Three phase current is obtained by arranging three similar sets of coils so as to divide the angular space corresponding to a pair of poles into three equal portions. Three equal E.M.F.'s are obtained, differing in phase by 120°. The three sets of windings may be connected in "delta" (Δ) or "star" (Y), and in either case only three slip rings or collecting terminals are needed for connection to the external circuit.

The two methods of connecting armature windings of 3 ph. generators, stator windings of 3 ph. motors, or the three phases of other receiving appliances are illustrated in Fig. 14 (*star connection*) and Fig. 15 (*mesh, delta,* or *triangle* connection). Since the algebraic sum of the instantaneous values of the currents in a balanced polyphase system is always zero, only three line wires are required for 3 ph. distribution. With the star method of grouping, the line currents are equal to the armature currents in corresponding phases, but the voltage between pairs of line wires is $E = e\sqrt{3} = 1{\cdot}732\, e$. With mesh or delta grouping the line pressures are the same as the armature pressures; but the line currents are 1·732 times the armature currents. Star connection is usual in high voltage work.

Alternator E.M.F.'s.—The formula for the E.M.F. induced in each phase winding of an alternator is as follows—

$$E = k\,Z\,N\,f \times 10^{-8}$$

in which Z is the number of armature conductors connected in series in each phase winding, N is the magnetic flux per pole, f is the frequency, and k is a factor the magnitude of which depends upon (*a*) the number of slots per pole per phase, (*b*) the ratio of the polar arc to the pole-pitch, and (*c*) the shape of the pole-shoe.

The following table of values of k, given by Mr. C. C. Hawkins, has been calculated on the assumption that the air-gap length (single) is equal to $\frac{1}{20}$th of the pole-pitch, that there are two slots per pole per phase, the slots being spaced $\frac{1}{6}$th of the pole-pitch apart, and that the width of the pole-shoe is equal to the width of the pole or field-core.

k=2·48	2·26	2·10	1·93
when $\frac{\text{pole arc}}{\text{pole pitch}}$=0·30	0·50	0·70	0·90

ALTERNATING CURRENT MOTORS.

Both single-phase and polyphase motors may be divided into two distinct classes—*i.e.*, *synchronous* and *asynchronous* motors. The synchronous motor, as its name implies, is one which runs perfectly "in step" or "phase" or synchronism with the alternating current supplied, and consequently runs at a constant speed. The asynchronous motor, on the other hand, is one which does not run in synchronism with the alternating current, but whose speed varies slightly with changes of the load. The synchronous motor is simply an alternator reversed, which, when its armature is supplied with an alternating current and once run up to a constant speed so as to be in synchronism with the generator, and has its field-magnets excited with a direct current, may be fully loaded and do work without being thrown out of synchronism. For power work where constancy of speed, continuous and steady running with variable torque are essential features, as in textile factories, the synchronous motor is perfectly adapted. But there is a limit to its use: (1) It is not suitable for cases where the power has to be divided into separate and small units; (2) it is not self-starting without special devices, as it has practically no initial torque; (3) there is a limit to the load which it will take, and it is liable to sudden stoppage by a temporary over-load, throwing it out of synchronism. The separate excitation by continuous current is also a disadvantage; many devices, however, have been introduced to render the single-phase synchronous motor self-starting, and in this way its sphere of usefulness has been considerably enlarged.

In consequence of the above disadvantages the two-phase and three-phase *induction* motors have become formidable rivals. The distinguishing features of induction motors are (1) the rotating magnetic field, and (2) the initial torque due to the inductive action of the closed or short-circuited coils of the moving element which is termed the *rotor*, the stationary element being known as the *stator*. The principle of action of the induction motor is analogous to the inductive effect produced in the static transformer. The stator windings are similar to the armature windings of a polyphase generator, the conductors being placed in slots on the inner periphery of a hollow cylindrical and laminated iron core, and no rubbing contacts are required. When the stator winding is supplied with three-phase currents of the same amplitude and possessing a phase relationship of 120°, the resulting magnetic fields combine and form a rotating magnetic field of fixed magnitude and angular velocity.

The rotor conductors are embedded in slots or holes on the outer periphery of a laminated cylindrical core placed within the

stator core, and from which it is separated by a very small air-gap. In its simplest form the rotor winding consists of a number of stout copper conductors which are electrically interconnected at both ends by annular copper rings, giving the general appearance of a squirrel-cage, so far as the conductors are concerned, and for which reason this type forms the squirrel-cage rotor. There is thus no electrical connection between the stator and rotor winding, nor between the rotor circuit and an external circuit, consequently no slip-rings are required.

The squirrel-cage rotor is defective in that its power-factor just at starting is bad, and as this interferes with the pressure regulation of the circuit it is used mostly in the case of small motors. For large motors, and for introducing resistance in the rotor circuits so as to obtain speed variation and improved starting torque, the rotor winding is formed of three sets of conductors connected as a star-grouping in connection with three slip-rings and brushes, in a manner somewhat similar to the stator winding. In this way resistance may be inserted in the rotor when desired, and the scope of the motor as regards speed variation is enlarged. Such a motor is said to have a distributed winding for the rotor, and is known as the *slip-ring* motor.

ALTERNATING CURRENT GENERATOR AND MOTOR TROUBLES.

The following notes refer to defects and troubles peculiar to a.c. generators, synchronous and induction motors. Notes relating to brush gear, bearings, lubrication, oil leakage, etc., are equally applicable to d.c. and a.c. machines.

General.—Appoint a competent man to examine all machines for mechanical and electrical defects at regular intervals. Signed tabular report sheets are worth compiling. *Hot Bearings.*—See that oil is clean, sufficient and properly distributed; check alignment of motor and load; reduce excessive belt tension. *Supply Defects.*—The effect of low voltage is discussed below. Unbalanced line pressure (common in unbalanced industrial circuits) reduces maximum output of motors, produces unbalanced phase currents and may blow fuses in one phase.

Hunting. *Generators.*—Increasing flywheel inertia reduces liability to hunting but prolongs latter once set up. Engine governors should have dashpots to prevent response to cyclic irregularities: too slow governor operation, however, aggravates hunting. Synchronising engine crank is sometimes useful, but takes time and is apt to aggravate hunting of synchronous motors in distant substations. Damping coils or grids are effective and often necessary on gas driven but rarely on steam or water

driven alternators. *Synchronous Motors.*—Hunting generally due to cyclic irregularity of speed in the engine driving the supply alternator. Trouble aggravated by high line resistance and may be cumulative or limited. Cumulative hunting will soon pull the motor out of step. Damping coils or bridges in or between poles generally effective; fitting them is matter for maker. Try weaker field current. *Induction Motors.*—Hunting rarely occurs. Generally depends on unfortunate combination of line drop and peculiarities of motor design. Manufacturer responsible. Try reducing line resistance and changing connection and grouping of phases. Cumulative hunting causes shutdown or breakage.

Alternator Troubles. — General mechanical and electrical defects common to all electrical machinery; *see* D.C. Defects. *Low E.M.F.*—Switchboard instruments may be in error; test by standard instrument. Generator speed may be low or excitation weak. Latter trouble is due to deficient exciter voltage (low exciter speed; wrong brush adjustments; reversed series or shunt field coils; or short circuited shunt coils). Increase exciter volts or remove resistance from generator field circuit. It is difficult to maintain correct voltage when supplying loads of poor power factor; improve latter by using synchronous motors or Kapp vibrators and avoiding loads of low p.f. (chokers, squirrel cage induction motors under heavy load, etc.).

Synchronous Motors. *Starting.*—Failure to start generally due to excessive load; try to start quite light before seeking other trouble. Two and 3 phase motors are self starting against no or small load, providing no phase connection is open. The machine starts as an induction motor; no field excitation is required during starting (which is generally impossible under full field). Special starting windings or pole bridge pieces facilitate starting. Reduction of voltage by low power factor may prevent starting or trouble may lie in open or faulty connections in auxiliary apparatus. (Incorrect rotor connections lead to unbalanced circuits and failure to start.) Open circuit in machine itself indicated by no current in phase affected. Short circuit indicated by excessive current; may be due to two earth faults; if left will cause burn out. Operation may be continued temporarily with single coil burnt out.

Armature Troubles.—Overheating indicates excessive armature current; reduce load or do less in way of power factor correction. If starting torque abnormally low, trace or check connections. Currents in armature phases should be roughly equal when rotor is turned slowly; unequal currents with rotor stationary do not necessarily denote a fault. *Field Troubles.*—If field weak or defective, check exciter volts; look for open circuit in field or regulator; check polarity of field coil connections. Field coils are exposed to high induced pressure when starting, particularly

if not then subdivided by switch; this may cause insulation breakdown and subsequently short circuit. Interruption of field during working causes shutdown or bad armature heating. If field current required appears excessive, test polarity of armature coils for reversed connections.

Induction Motors. *Starting Troubles.*—If machine refuses to start examine fuses. Try reducing load; squirrel-cage motors have limited starting torque; start light or by clutch if necessary. Starting resistance with wound rotor may be insufficient; see that starting switch is in starting position (*see* Rotor Switch). See that voltage is normal and bearings and rotor not seized. Test for open circuit in wound rotor. Excessive current at starting, due to too high stator volts or load. Reduce load, use autotransformer or lower tapping from latter. Do not use lower tapping than required to start satisfactorily. If autotransformer wrongly connected, starting current is excessive and running output is very low, only reduced voltage being available. *Slow Running.*—Generally an induction motor runs about 4% below synchronism (synchronous R.P.M. = (120 × cycles ÷ no. poles). Greater slip is due to excessive load or high resistance in rotor circuit—whether in windings or at brushes. If the machine starts well but will not carry load at certain speeds, the fault probably is due to " magnetic locking " between rotor and stator teeth. There is no remedy; machine should be refused. *Machine Stops.*—*Overload* may cause unstable state in which motor comes to rest and takes 10 × normal current. If fuses or circuit breaker do not immediately operate, the machine will burn out, since heating varies with square of current. Torque varies with square of voltage, hence *low volts* may cause machine to stop. When starting under low pressure, starting torque is much reduced; use larger transformers or leads or both. If the rotor fouls the stator (due to bearing wear) the machine will stop or must be stopped.

Autotransformer Troubles.—Reversed autotransformer connections give excessive starting current and insufficient torque with switch in running position. Refusal to start may be due to defect in change-over switch; loose connections or open circuit in transformer. Try a higher tapping, but watch ammeter meanwhile. Opposition of sections of transformer windings by wrong connections reduces applied voltage, even to zero.

Increasing Maximum Output.—If motor refuses to carry load required but is in order as regards bearings, gap and voltage, etc., it may be overrated by the makers (*i. e.* incapable of developing power stated on name plate) or, more probably, the load has been understated in ordering. A more powerful motor is the only

permanently satisfactory solution, but extra power can sometimes be got safely for a time by changing the primary (stator) connections. In a 4-pole motor (no. of poles = 120 × cycles / sec. ÷ R.P.M.), by connecting the two windings of each phase in parallel instead of in series, the voltage per coil is doubled and the output quadrupled (barring increased percentage losses). Exciting current is increased; and efficiency and power factor reduced by such change. Take care that same direction of current flow is preserved after connections are altered; also note whether windings overheat seriously under altered connections—if so, machine must be stopped. If coils are already in parallel, no increased power can be obtained except by transforming up supply pressure; this may cause insulation breakdown. In a *three-phase motor*, connecting coils in parallel instead of in series doubles the pressure applied to each; changing delta to star connections reduces pressure to 0·58 × line volts; changing star to delta increases phase voltage 1·73 times.

Mechanical Defects.—Largely same as for d.c. machines, but special attention is required by the bearings. Air gap round rotor is often 0·02–0·04 in., hence any appreciable bearing wear causes rotor to foul stator. Bent shaft introduces same risk. Insufficient end play to allow for axial magnetic or belt pull may cause excessive friction and heating at thrust or shaft collar. It should be possible to press the shaft to and fro axially $\frac{1}{8}-\frac{3}{16}$ in. while running. Increase end play where insufficient; correct end thrust by aligning belt; in small machines drive rotor teeth over in direction of thrust or stator teeth in opposite direction; use wooden block; work on whichever set of teeth is longer and narrower.

Rotor Switch.—In machines with wound rotors, see that rotor short-circuiting switch is in order, particularly if internal (*i. e.* carried by the rotor itself). The switch should automatically or by interlocking return to position inserting rotor resistance when machine is stopped; if the switch opens while machine is under load, motor will slow or stop.

Electrical Defects.—Incorrect, defective or broken connections are indicated by local heating of coils, irregular sound, heavy and unbalanced currents. Stator connections may be reversed; some stator coils may be short circuited. In "wound" rotors, one or two phases may be reversed. In squirrel-cage motors, rotor defects rarely occur; soldered joints may melt or corrode; brazed, riveted or cast joints should be used. Failure of such joints produces uneven running; high resistance at all joints lowers efficiency, increases heating and increases starting torque. If one stator phase be open, a 2 or 3 phase machine will run at reduced output if started light and helped under way.

ELECTRIC MOTORS IN INDUSTRIAL SERVICE.

Electric Motor v. Steam Engines, etc.—It is generally more economical and convenient to use an electric motor served by public supply mains than it is to install and operate private power plant. Modern central station plant is so efficient and forms the special object of such careful operation that private plant can rarely compete, even allowing for the fact that the central station sells energy for profit. Private plant is in a favoured position if there is waste material available for fuel, if large quantities of steam are required for industrial purposes, or if there is a useful application for waste steam or hot gases from oil engines. The general tendency, however, is to underestimate the direct and indirect cost of private plant; apart from fuel and wages costs there are maintenance, interest and depreciation charges, and the risk and responsibility of private power plant to be considered, as well as the capital and floor space which might be devoted to the power user's own trade or industry.

When an existing engine is replaced by an electric motor it is not advisable merely to substitute the motor for the engine. The engine speed is generally lower than the economical speed of an electric motor of equal rating, and a yet more important consideration is that the electric motor is a power unit which can be subdivided almost indefinitely without serious loss of efficiency and with much lower increase in investment per horse-power than would be involved by attempting to subdivide prime mover equipment in the same way. A factory may employ a hundred electric motors each of 1 h.p. with perfectly satisfactory results (better than attainable by other means), but an equal number of steam engines of equal rating would be hopelessly inefficient and costly to operate and maintain.

A good rule is not to presume upon the present-day excellence of the electric motor and its auxiliaries. The whole should be given systematic inspection at regular intervals (shorter the more severe the service), and a record should be kept of all difficulties, defects and breakdowns. Special attention should be paid to cases of recurrent trouble.

Power costs form generally a low percentage of total operating expenses; it is foolish to stint power, but every rational economy in power utilisation is worth while. Light load power consumption should be kept a minimum as regards horse-power and duration.

Arrangement of Drive: Group v. Individual.—The heavy shaft and belt systems used where a single engine drives a large

section of a works are quite out of place in electric driving. At the most a motor should drive a comparatively small group of machines, and the tendency is towards individual drive with the motor "built in." Two classes of group drive may be distinguished : (1) a number of machines which, between them, make up a reasonably steady load of lower horse-power than the sum of the individual horse-powers; (2) a number of machines all on the same work for the same hours, so that the group horse-power is greater than the sum of the individual horse-power (by the losses in lineshaft and belting), but the group motor is of lower cost and higher efficiency than the alternative group of small machines.

If reasonably constant average load is not obtainable from a group of machines of various powers, these had better not be driven by a single motor and lineshaft, otherwise the overall efficiency will be low and the power bill will be much the same whatever the useful work done, because a large fraction of the total energy consumption goes to drive idle shafting. A useful idea to improve load factor where not all the machines in a group need be used at once is to have a large scale ammeter connected in the mains supplying the group motor and located where it can be seen easily from the larger machines in the group. Operators can then see whether starting another machine at a given moment will bring the total load above a predetermined value indicated by a lubber mark on the ammeter scale. This arrangement is particularly useful when working from private generating plant or when working under a supply tariff which is based on maximum demand. In most cases and particularly under present conditions, it is not worth while to sacrifice output in order to keep down the maximum demand, provided that the latter can be supplied without overloading generating plant. On the other hand, a breakdown or temporary interruption of working is generally more serious and costly than a slight reduction in the sustained output. If output cannot be maintained without risking breakdown the true remedy lies in more or better plant.

Peak loads on individual machines form a less percentage of the motor h.p. with group than with individual drive, and may be compensated entirely by concurrent low demands from other machines in the group. On the other hand, concurrent peak loads are not eliminated entirely by group driving. The more scattered the plant the more likely is individual driving to be better, especially as machines in scattered plant often operate more or less independently of each other. Such machines as rolling mills should be driven individually in order to obtain full control over the large quantities of energy concerned. Also,

electrical transmission of energy is cheaper and more efficient than mechanical transmission in such cases. It is costly, both in initial and running expense, to use a larger motor than is required for the mean load, and, particularly in individual drives, flywheels should be used whenever possible to deal with peak loads. An advantage of the "built-in" motor is that it saves parts and floor space compared with belt or gear drive, and also gives better efficiency. Co-operation is needed between the makers of the motor and of the driven machines. Nothing in the excellence of the combination should be sacrificed for the sake of using a standard motor. The aim should be to standardise the best combination of machine and built-in motor, if the latter be used at all. A direct coupled or built-in motor eliminates belt slip with resultant loss of power, depreciation and delay in reversal, and makes possible electrodynamic braking and rapid reversal without shock. The conversion of an existing machine to electric drive is generally accomplished most easily by belt or gear coupling. The latter permits of a higher motor speed and lower range of speed control in the motor itself, both of which factors cheapen the motor. It is sometimes convenient to hang motors from the ceiling and drive machines on the floor above by belting through the floor.

From tests on miscellaneous wood-working machinery, Clewell estimates that individual driving in this service yields 5 per cent. higher average speed than lineshaft and belt drive; yields 20 per cent. higher production; and eliminates the 40 to 75 per cent. loss otherwise incurred in lineshaft and belting.

A variable speed, direct coupled, reversible motor, with automatic or manually operated reversing switchgear, is far preferable to stepped pulley, belt and clutch, or coupling combinations. Belt loss and wear are eliminated; the cost and inertia of a countershaft are saved; and the motor is a lighter and more economical machine than otherwise required. Electric control gives flexibility of speed variation, braking and reversal which cannot be obtained mechanically; also, the cutting and reversing speeds can be varied independently. Smoother and more gradual control means greater and better tool output and less depreciation of machine. In certain planer tests, the light load power consumption was four or five times as great with belt as with direct electric drive, and the latter gave 40 to 50 per cent. more cutting work per minute. A point which is often overlooked is the inertia of a high-speed armature and the importance of small armature diameter in a reversing motor.

Motor Construction.—Due to the use of improved materials and improved manufacturing processes, the modern electric

motor is remarkably light, efficient and reliable. Standard machines are available to meet practically every requirement. Action has been taken in France in the standardisation of motor shaft-end details so that these may be the same in all makes of motor; this will facilitate fitting, reduce the necessary stock of spares, and save delay and expense. Ball bearings reduce the axial length of a motor by from 10 to 30 per cent., the length of a ball bearing being about $\frac{1}{3}$ the shaft diameter, compared with $2\frac{1}{2}$ to 3 *d*. in the case of ordinary bearings. The efficiency of a ball bearing is higher; the attention required is very slight; and maintenance and repairs are almost nil. The risk of oil getting on to commutator and windings is eliminated, and the absence of oil prevents accumulation of dust, fluff and shavings, etc.; on the other hand, the ball bearing must be packed with grease to exclude dirt. There being no appreciable wear in a ball bearing, a very small air gap may be used safely (*e. g.* in induction motors) and accurate meshing of gear wheels may be maintained, thus reducing wear and increasing efficiency. The shortness of the bearing reduces the overhang of pulley or pinion, and its great strength and rigidity resist accidental or sustained high stress where gear or belt drive is employed.

The cost of large concrete foundations may be reduced without undue sacrifice of strength or mass by burying old pipes or even wooden barrels in the concrete. Where a perfectly solid foundation is required, it may still be cheapened by the judicious inclusion of large stones well rammed in the concrete.

Motor Enclosure.—The following notes relate to the various degrees of enclosure recognised by the B.E.A.M.A. (1) *Open type* motors have no enclosure or protection other than that provided by the stator frame and the arms carrying the bearings therefrom. Such motors are restricted to service in clean, dry interiors unless : (*a*) The motor is protected from dust by a suitable enclosure such as a wooden box lined with sheet iron. It should be noted that the rating of an open-type motor is materially reduced even by such partial enclosures as a ventilated box. (*b*) The insulation is such as to withstand moisture, and no special mechanical protection is required. An extreme example of a motor of this type is the *submersible* motor which is an a.c. induction motor designed and insulated to withstand indefinite submersion in water. (2) *Protected motors* have their field coils, armature and commutator or slip rings protected from accidental access or mechanical injury without, however, material obstruction to ventilation and cooling. The latter stipulation necessitates that the protection be by expanded metal or wire netting of quite large mesh; if the area of the protecting metal be more than say 15 or 20 per cent.

of the area protected, the rating of the machine is almost certain to be lowered. (3) *Enclosed-ventilated* motors are one stage nearer to enclosed machines. There are openings in the frame specifically for ventilation. These openings are small compared with the openings in open-type and protected machines, and their value as regards ventilation is further reduced if they be covered by a mesh less than $\frac{1}{4}$ inch. If the mesh of the covering be less than $\frac{3}{32}$ in. or if perforated plate with holes less than $\frac{3}{16}$ in. diameter be employed, the motor rating will be no higher than that of a totally enclosed machine. (4) *Pipe-ventilated* motors are totally enclosed except for two apertures in the casing, viz. the inlet, to which a pipe is attached for the incoming ventilating air, and the outlet to which a pipe may or may not be attached for the outgoing hot air. The rotor of the ordinary pipe-ventilated motor is provided with a fan, which draws air in through the inlet pipe, the latter being merely led to some point where dry, cool air is available. The reduced pressure necessarily established by this fan within one end of the casing, will draw oil in from the bearing at that end unless the bearing be entirely inside or outside the end shield of the motor. Care must be taken that the inlet pipe does not offer so much resistance to air flow that the rotor fan is unable to draw in an adequate supply of cooling air. If the heated air be conveyed away through a pipe line the resistance of the latter has also to be overcome by the fan. The *forced-draught* pipe-ventilated motor offers obvious advantages, an independent fan of adequate capacity being used to force air through the machine. (5) In *drip-proof* motors, the ventilation openings are protected so as to prevent ingress of dripping moisture or dirt, etc. (6) In *totally enclosed* motors it is not possible for air to circulate between the inside and outside of the casing. This type of machine is used in very dirty service. Heat is removed only by conduction through and convection and radiation from the casing, hence the rating is much lower than that of an open machine of equal dimensions. A material increase in rating is obtained whilst retaining the feature of total enclosure in the " Encol " enclosed-ventilated motor. The air inside the motor casing circulates through channels in the stator frame, adjacent to other channels through which air from outside is driven by a fan on the motor shaft extension. There is no air circulation between the inside and outside of the casing, but the cooling surface is increased, as also is the volume of outside air sweeping this surface. Another way of obtaining the same result is to fit a circulating fan on the motor shaft to drive air through the ventilating ducts of the machine, and back through a tubular radiator mounted on top of the motor. Ordinary enclosed motors are uneconomical machines owing to their relatively low rating.

(7) *Flame-proof* or *explosion-proof* motors are designed to withstand explosion of gases within the casing, and to prevent transmission of flame through the casing joints to the surrounding atmosphere. These results are secured by mechanical strength in the casing to resist internal pressure, and by wide close-fitting joints to ensure that escaping gases are cooled below ignition temperature before they reach the outer air. It is important to realise that " total enclosure " is only a relative term where motors are concerned. Air from outside is inevitably drawn in through the casing joints and bearings by the alternate heating and cooling of the motor, so that the only safe policy in explosive atmospheres is to allow for explosions occurring inside the motor casing, and to prevent flames being driven through the joints.

Choice of Motor.—Though a motor should be capable of running continuously at its full rated output (excepting motors rated for intermittent service) it is not advisable to run the motor continuously at full output. The power factor of a.c. motors and the efficiency of all motors should be a maximum or nearly so at three-quarters full load. It is a liberal but not unprofitable policy to choose motors so that they operate normally at about three-quarters their rated output. It is often worth while to replace old motors by new improved designs, the new motors being lighter and more efficient and costing less for inspection and maintenance. The price of a motor varies approximately with its weight, which varies inversely with speed; if the speed exceeds 1000 r.p.m. the saving in first cost is liable to be more than balanced by increased cost of bearing maintenance, especially where belt drive is employed. The horse-power from a given carcase varies with speed. It is not every motor on the market which is satisfactory in point of shaft diameter, bearing size and pulley overhang. Ball bearings are worth while in small motors, especially if there is to be much running light. A third, " outboard," bearing should be provided if the drive is very heavy or the overhang long. Certain of the I.E.E. wiring rules relate to the installation of electric motors; and the E.S.C. British Standardisation Rules for Electrical Machinery contain much useful material. According to circumstances reference should be made to the I.E.E. Wiring Rules; B.O.T. Regulations; H.O. Regulations for Factories and Workshops; H.O. Rules for Mines; L.C.C. (or other local authority) Regulations for Theatres, etc.

When choosing a motor, it should be seen that its starting characteristics as well as its load characteristics are suitable. Generally, d.c. motors are better than a.c. motors for industrial service. D.C. motors are superior in point of wide speed control and high starting torque. An advantage of a.c. is the simplicity

and efficiency of isolated transformer substations. D.C. cannot be distributed conveniently at such high pressures as a.c., and a.c.–d.c. converter plant is more costly than a static a.c. transformer of equal rating. The cost of wiring for 440 v. motors is considerably lower than for 220 v. motors. Polyphase induction motors are about 20 to 30 per cent. lighter up to 10 h.p., and 15 to 20 per cent. lighter from 10 to 50 h.p., than d.c. shunt motors. For group driving a constant speed (shunt, compound or induction) motor should be used on the lineshaft. The simplicity, strength, low first cost and economical maintenance of 3 ph., 50 cycle squirrel-cage motors make the latter very suitable for any industrial service in which constant or nearly constant speed is required; these motors will take sudden variations in load up to twice rated torque with relatively small change in speed. Interpole compound motors with small armature inertia are suitable for reversible drives. *D.C. Series Motors* yield high starting torque and decrease in speed with increasing load. They are suitable for cranes, hoists, heavy tool slides and traction service. They race on light load, hence must never be used where the load may be removed. The degree of racing depends upon the design of the motor; generally the light load speed is three or four times the full load speed. *D.C. Shunt Motors* are applicable where the requirements are constant speed and torque, constant speed and moderate variations in torque, or constant torque and varying speed. For constant torque service use variable voltage control and calculate h.p. on min. speed. For constant power variable speed working use field control. An interpole shunt motor is capable of wide speed variation with little sparking. Shunt motors are suitable for small printing presses, ventilating fans, small machine tools and adjustable speed work on heavier tools, *e. g.* lathes, boring mills, etc. *D.C. Compound Motors* yield high starting torque, are able to deal with sudden wide load variations, and are not liable to race on light load. A compound motor with flywheel is suitable for planers, shears, punches and other machines with sudden heavy loads and low, steady load between whiles. *A.C. Synchronous Motors* are suitable only for steady load at constant speed (*e. g.* colliery fan). The power factor may be made unity or leading, and these motors are sometimes used solely for p.f. correction. They may be connected directly to a.c. supply at 10,000 v. or higher pressure, but d.c. is needed for excitation. The efficiency is high, but starting is more or less troublesome, the starting torque is low and there is considerable risk of hunting and of pulling out of step on variable load, but modern synchronous motors are much improved in these respects, and their use in industrial service is extending rapidly. *A.C. Induction Motors.*—With squirrel-cage rotor the

characteristics and applications resemble those of d.c. shunt motors. With wound rotor and adjustable rotor rheostat the characteristics and applications are those of a d.c. compound motor; high starting torque may be obtained and flywheel storage employed. Pole-changing induction motors provide a few definite speeds conveniently and efficiently. *A.C. Commutator Motors.*—Special types are available for all classes of service, including lifts and traction. Repulsion motors are suitable for constant torque at variable speed but not for constant output and wide speed variation. A.C. series motors are very similar to d.c. series motors save that commutation introduces special problems.

Electric motors are now available or can be designed for practically any service. The largest motors and the most severe conditions of service are probably to be found in iron and steel works. For instance, a 20,000 h.p. machine built in this country for driving a rolling mill consists of three motor elements on one shaft; it is operated at 400 v., d.c. and weighs 300 tons. A 700 h.p. motor with 250 per cent. momentary overload capacity built in America to operate a 1200 ton bloom shear, accelerates, runs at full speed for $\frac{1}{2}$ sec. and comes to rest, the complete cycle occupying $2\frac{1}{2}$ secs.

Starting Torque.—A common cause of disappointing motor performance is underestimation of the starting torque required by the driven machine; this is particularly the case where induction motors are employed, because this type of motor does not give a high starting torque unless special means are taken to secure it. A motor starting on an open clutch or loose pulley may truly be said to "start light," but if the motor is coupled during starting, to a machine or length of shafting, the "light load" may be far from negligible. In order that the motor and control gear may be suitably proportioned it is necessary to consider the exact nature of the load and the conditions of starting and operating. If the starting current and time can be predetermined by a test motor and recording ammeter, so much the better. The following figures show approximately the rela-

Induction Motor Started by	Times Rated "Full Load" Value.	
	Starting Torque.	Starting Current.
Star-delta method	·25 to ·4	3 to 4
Autotransformer: 40 % line volts	$\frac{1}{6}$	$\frac{3}{4}$ to $1\frac{1}{8}$
60 % „ „	$\frac{1}{3}$	$1\frac{3}{4}$ to $2\frac{1}{2}$
80 % „ „	$\frac{2}{3}$	$3\frac{1}{4}$ to $4\frac{1}{2}$
Stator resistance	$\frac{1}{10}$ to $\frac{1}{4}$	2 to $2\frac{1}{2}$
Switching straight on	$\frac{3}{4}$ to $1\frac{1}{4}$	5 to 7

tion between current and torque for induction motors started by various methods; it will be seen that the starting current may be considerably greater than the rated "full load" current, hence if the motor is to be protected by fuses these must be so arranged that they are not in circuit during the starting period, *e. g.* they may be placed in the leads connected to the "running" terminals of a change-over switch.

The permissible starting current, the frequency of starting, and the efficiency of operation all affect the choice of polyphase induction motors. Starting with resistance in series with the primary winding results in at least five times rated current being taken to yield rated torque, but there is no rush of current such as that caused by changing over an autotransformer switch. When a torque exceeding rated full-load torque is required any of the methods of starting tabulated above, lead to current values which are usually not permissible. Voltage fluctuation when starting induction motors may be due to excessive current being demanded or to low-power factor of the motor affecting the regulation of the supply alternator or transformer. Since the motor torque varies with the square of the applied voltage, the intended voltage must be maintained as accurately as possible *at the motor terminals*, otherwise the starting torque and maximum power are reduced seriously. Excessive line resistance or high reactance in transformers and line causes reduced voltage, and hence lowers the starting torque and overload capacity. Three-phase cable, or three wires within the same conduit, give lower line reactance than open wires; single conductors through independent metal conduits give high reactance. A transformer with 4 per cent. reactance yields good voltage regulation, but 10 or 15 per cent. transformer reactance results in serious loss of motor capacity.

Supply Circuits.—The economical operation of any industrial power installation depends largely upon the use of suitable switchgear and suitably laid-out supply circuits. The centre of distribution should be as nearly as possible at the centre of gravity of the load, and as this is subject to more or less rapid change the distribution system should be flexible. Subject always to the primary requirements of safety and reliability, the permanent cables should be arranged so that any desired addition to, or modification of, the industrial installation can be made without having to consider electrical rather than manufacturing requirements. Ironclad industrial switchgear built up on the sectional plan should be used in preference to the less flexible system of slate or marble panels with rigid bus-bars. The ironclad switches may be mounted on angle-iron frameworks or behind steel panels, and, by using insulated cables for all connections, maximum compactness and flexibility are secured. Standard components

can be used economically to build up any desired control gear. Portable substations have many applications, particularly in the heavier industries (*e. g.* coal mining) with changing load centres. Free use should be made, in all industrial establishments, of portable test panels equipped with recording instruments, the records from which are invaluable in detecting irregularities and waste.

The correct fusing of motor circuits is an important consideration, especially where the starting current is relatively heavy. An American firm recommends that fuses which are in circuit when starting motors should be rated to carry the following currents (expressed as a multiple of normal full-load current) :—Direct current or polyphase wound-rotor motors, $1\frac{1}{4}$; single-phase repulsion motors with rheostat, 2; squirrel-cage motor, thrown straight on to the line, 3; single-phase repulsion motor started without rheostat, 4 times normal full-load current. If the starting fuse be rated for more than twice full-load current it yields no adequate protection during running periods, and, in such cases, the heavy fuse used during starting should be cut automatically out of circuit, in favour of a fuse rated at $1\frac{1}{4}$ to $1\frac{1}{2}$ times normal full-load current, after starting is completed.

Motor Control.—Apparatus used for this purpose is discussed in a separate section. A wide range of speed is generally needed to cover all tool sizes, work materials, depth and width of cut, etc., and if speed control be not continuous it should be by definite steps suitably graded for the work in hand. Control may be entirely by field regulation in a d.c. shunt motor, but the machine is large and costly for wide speed range. Alternatively, from $1\frac{1}{2}$ to 3 : 1 speed range may be obtained electrically and the remainder by two-speed countershaft. By overlapping the speed ranges on each pulley full control is secured over the whole range; retaining a belt at one point in the drive gives a degree of flexibility which is often valuable. Two definite speeds, *e. g.* cutting and reverse for planers, are obtainable with d.c. shunt or compound motors by automatically cutting resistance in or out of parallel with the field, or by connecting first one and then a lower resistance in parallel with the field. Regenerative braking is useful, but it will not *hold* a load. Electro-dynamic braking is practically nil below about half-speed in the case of a series motor, and a shunt field is desirable to maintain the braking effect. Induction motors up to 3 h.p. (10 or 15 h.p. in large industrial systems) may be used without special starters; switching straight on to the mains has the advantage of high starting torque, but the heavy rush of current is the limiting factor.

Motor starters are available with automatic or semi-automatic

devices which make the gear as nearly possible foolproof whatever the operating conditions. Judicious application of such devices permits motor control to be carried out at the maximum speed consistent with safety. Efficiency and output are increased; damage and depreciation are reduced; variable conditions are taken automatically into account, and either the whole operation is automatic or safety limits are imposed on what the operator can do. Starting gear may be obtained to give: (1) no speed control; (2) constant speed during the job but regulable speed as from job to job; (3) complete speed control at all times. Provision may also be made for reversal when required, and the safety features incorporated include interlock to ensure that variable field d.c. motors are started with full field, or a device to limit the armature current when starting with weak field; also a device to prevent generator action taking place when the field is suddenly increased (the armature speed being high at the moment).

Self-acting control gear may be actuated by push button or by float or trigger, and timed by air- or oil-dashpot or by a "current limit" relay. If the load varies between wide limits, control by time element is advisable. Press buttons or other master switches may be located anywhere and used to control any amount of gear within reason. Acceleration and deceleration are then graded properly and automatically; electrical and mechanical shocks are eliminated and current is economised. Control may be made entirely automatic by using trigger master switches actuated by the machine itself, instead of manually operated press buttons. This system of control is used principally on planers, slotters, boring mills and certain types of lathe. Accuracy of manipulation is ensured and the output is higher than obtainable by any other means.

Various automatic control features embody solenoids which may be connected either "full on" or "through resistance." This is a useful arrangement because it provides a maximum pull capable of closing or opening a switch or a weaker pull capable of holding the switch, but not of changing its position until full excitation is produced by short circuiting the series resistance.

Manually operated starters with no other automatic features than overload and no-volt releases are still used in great numbers. Where these are used, the arm should be held on each notch until the maximum speed for that notch is reached (as indicated by the steady hum) or until the current is constant (as indicated by an ammeter in circuit). "Inching" is specially injurious to starter contacts unless an automatic device is embodied to transfer all current breaking to a contactor designed for that

service. A starter which is not designed for use as a speed regulator should not be used for "inching," or it will probably overheat. Sparking tips require more attention in d.c. than in a.c. gear; they should separate *after* the main contacts, otherwise they cannot shunt current from the latter. Pitting of the sparking tips is no cause for anxiety so long as they serve their purpose and keep the main contacts free from sparking; new tips must be fitted as often as necessary. If any sparking does occur on the main contacts these should be massive enough to absorb a considerable amount of heat and to allow for smoothing the contact face at intervals; the contact brushes should be automatically or otherwise adjustable. It is not always recognised that a switch which will break 100 or 500 amps. in a non-inductive circuit will be incapable of breaking more than, say, 20 or 50 amps. in a circuit which includes solenoids or other highly inductive apparatus. Even a length of steel armouring or conduit may be responsible for sufficient surge voltage to maintain the switching arc, which would otherwise be broken.

Overheating in a motor starter may be due to the ventilation being less than anticipated by the designer, owing to the starter being erected in a wrong position (*e. g.* horizontal instead of vertical), or in a confined space, or where dust, etc., clogs the air holes. Dust in particular is very dangerous, because it may be ignited by the overheating which it causes; totally enclosed starters should be used in such cases. When there is ample time for the starter to cool before it is used again, the temperature rise for a single start may be accepted, but if the starter does not cool thoroughly before it is used again, the maximum temperature after a series of cycles must be taken as the basis of rating.

Liquid starters are rather cumbersome, but they are cheap to install and maintain, and if suitable circulation and cooling of the electrolyte be arranged, these starters are useful in controlling 3 ph. motors in heavy power applications. Leakage of electrolyte and variations in sp. gr. should be avoided. Generally it is preferable to have all the electrodes in one tank (rather than a separate tank for each electrode), otherwise there is a possibility of the rotor currents being unbalanced by variations in the quantity or density of electrolyte in the several tanks.

Where induction motors are started by compensators, care must be taken that the phase connections are complete from the running contacts, otherwise the machine may start polyphase and run as a single phase machine with unbalanced current and overheating. Sometimes the line and motor connections to the autotransformer are interchanged, with the result that the pressure applied to the motor is raised instead of reduced during

starting, hence the motor starts violently and the transformer is overheated. The oil level should be maintained in oil-immersed gear, and in particular all contacts should be submerged, not only to get the advantage of a head of oil in extinguishing arcs, but also to prevent open sparking in oil vapour. The slightest trace of moisture in oil (even that resulting from handling the oil in a damp atmosphere) greatly reduces its insulating value. Only the best oil should be used; high working temperature (due to bad contact or other cause) hastens sludging, which is easily detected by the oil becoming darker and forming deposits. The latter should be removed and fresh oil employed.

Safety Devices.—Some of these have been noted already. Overload releases should be tested by raising the plunger slightly so that the release then operates. This checks free working but not the adjustment, which can only be checked by an actual overload and an ammeter observation. In general, overload protection in a three-phase, three-wire system needs fuses or trip coils in three phases if the neutral be earthed, and in two phases if the neutral be insulated. A three-phase slip ring motor may be protected by a circuit breaker with two or three overload trips (as the case may be), and by one with a trip connected in the rotor circuit (protecting against an open stator phase or mechanical overload). No-volt releases should always be fitted and the working components kept clean and free. The coil may be connected to the line (and then takes current all the time the lines are live), or it may be connected "inside" the motor switch so as to take current only when the motor is running; this is generally preferable.

Current should be cut off by isolating or main switches before working on the circuit, and it should be kept "off" during such work either by an interlock or by locking up the switch or by mounting guard over the latter. Isolating switches should be provided so that either individual control gear or groups of gear can be isolated if necessary. A circuit may be kept "live" through a shunt trip coil, voltmeter or no-volt release, even though the main switch be open. Casings and frames should be earthed and the efficacy of earthing tested periodically. A fatal accident has been caused by a piece of loose steel in a motor starter box being made to effect contact between a live terminal and the casing by magnetic attraction exerted when current was flowing.

An American firm uses dynamic braking to stop electrically driven drills within $\frac{1}{4}$ rev. in case of need (*e. g.* work being carried round by a drill sticking in the hole). When the operator releases the machine control handle, a switch interlocked with the latter

reverses the series field of the motor and short-circuits the armature.

Power Required to Drive Machinery.—For obvious reasons it is only possible to give data which shall form a general guide to power requirements. Power requirements specified by makers of tools and machinery are frequently too low. H.P. of machine tools varies with tool steel, number of tools, and material worked upon; data given in the accompanying Table assume single tool and average modern conditions. Too small a motor means throttled output of tool and operator, and it is obviously better to pay for current usefully consumed than to limit the output of a costly tool. On the other hand, too large a motor means idle investment and poor efficiency. The power requirement of any machine may be measured electrically by metering the consumption of a motor which is of known efficiency and more than the power required, so that the best operating conditions may be found by trial.

Value of Recording Instruments.—Great improvement in the efficiency of motor drives results from the proper use of recording instruments. A record of power or current output (using for the test a motor which is known to be of ample power) makes possible accurate estimation of the minimum motor h.p. required and of the extent to which a flywheel may be used advantageously. Also the record shows whether time is wasted during the cycle (*e. g.* by belt slip or incorrect setting of trip gear), and whether the equipment is being worked electrically and mechanically with full efficiency and/or maximum output. Finally, the effect of various speed combinations and driving arrangements can be seen at a glance. By these means capital expenditure is reduced to a minimum and lowering in operating efficiency is detected promptly. A portable test board with recording wattmeter and ammeter is useful in keeping a whole installation up to full efficiency with little trouble and expense. The records obtained show where permanent connection of a recording ammeter is desirable to permit constant watch to be kept on operation which is much affected by the skill of the operator or the particular combination of working conditions. A useful feature in the recording instruments is variable speed of the paper drum so that the same instrument will give either a record of daily performance or a large-scale chart of individual cycles. The characteristics of the load are an important factor in any motor drive, and are best determined by graphic instruments in the circuit of a test motor of known ample capacity. In machines such as planers the machine-hour costs vary little

HORSE-POWER TO DRIVE MACHINERY.

	H.P.
Lathes—	
Screw cutting, 6in. centres	½
12in. ,,	1-2
24in. ,,	5
Engine, 2ft. swing, carbon steel	2
h.s. tool steel ..	7-10
4ft. swing, carbon steel	5
h.s. tool steel ..	15-20
6ft. swing, carbon steel	7
h.s. tool steel ..	25
Turret, allow about twice the power stated for s.c. lathe of same height of centres.	
Wood-turning lathes, 6in.-12in. centres	1-2
Face plate, 2½-5ft. ..	2-4
8-10ft. ..	7-10
Planers, etc.—	
Planers, 4-8ft. stroke ..	2½-5
10-15ft. ,, ..	7½-10
heavy	30-50
Shapers, light work, up to 30in. stroke	1-2
Slotters, 6in.-9in. stroke..	1-2
heavy	5-8
Milling Machines—	
Light	½-1
Medium	2-3
Heavy	5-10
Drilling, Boring, etc.—	
Light sensitive drills ..	¼-½
Pillar drill, 12in. table ..	1-2
Radial, 3ft. swing	2
Portable drills, up to 2in.	¼-2½
Boring mills, 3-5ft. table	2-3
9-10ft. ,,	8-12
Punches, Shears, etc.—	
Punches, medium	3-6
28in. shears, 3in. stroke	7
Shearing ⅝in. plate at 16ft./min.	15
Metal Saws—	
12in. circular, cold ..	2
24in.-30in. circular ..	4-6
Band (6in. mild steel) ..	4-6

	H.P.
Grinding—	
Grindstones 2½-3½ft. ..	1½-3
Emery, carborundum, etc., up to 12in.	½-1
12in.-30in...	1-3
Saw-sharpening machines	½-1½
Guillotine knife grinder ..	3½
Cup wheel tool grinder ..	5
Polishing lathe, light type	⅛-1
Double ended, 10in. wheels	2
Woodworking Machines—	
Circular saws, 12in. ..	2-4
24in.-30in.	10-15
48in.-60in.	25-50
Rip saw, 6in.-9in. hard-wood	15-20
Band saw, light work ..	2-4
2-3ft. logs ..	30-50
5-6ft. logs ..	60-80
Cross-cut saw, light type	2-5
heavy type	10-20
Fret saw, 6in.-8in. cut ..	1-2
Planers, light duty ..	2-4
heavy duty ..	10-15
Mortising machines, light	1-3
heavy	6-12
Boring machines	6-12
Tenoning machines ..	5-10
Moulders	3-6
Sandpapering machines ..	2-4
Textile Machinery—	
Bale breakers; openers ..	2-5
Beaters; scutchers ..	3-8
Carding engines; doublers; sliver lap; ribbon lap; combers; cloth presses (each)	½-1
Calico loom, 3-9ft. ..	⅓
Sailcloth loom, 5ft., 60-120 picks	1-1½
Lancashire loom, 40in, 180-200 picks	⅓-½
Spindles per H.P.—	
Slubbing frames ..	45-52
Intermediate	55-60
Roving frames	70-80
Ring frames	80-150
Doubling frames ..	20-50
Winders	200-300
Weft winders	100-150

HORSE-POWER TO DRIVE MACHINERY (*continued*).

Machine	H.P.
Paper, Printing, etc.,	
Breakers, beaters, paper-making machines and calenders..	25-50 up to 100 or more
Pulp crushers and refiners	100-250
Coating machines; dusters; wet pulpers; press plates	20-30
Elevators; cutters; dampers	5-10
Saws and barkers	10-20
Glazers; rulers	3-5
Average newspaper press, city	40-70
provincial	20-30
5½ deck Goss; 36000/20 pp./hr., main motor ..	50
Do., auxly.motor, inching, etc.	7½
Hoe machine; 24000/4 pp., 32 pp.	20, 120
Webb press; 12000/10 pp., 32 pp.	15, 30
Linotype	¼-½
Small jobbing press ..	¼-1
Letterpress, demy to double demy ..	2-4
double royal to quad royal	4-10
4-roller press, about 3 × 4 ft. bed	3-5
Guillotine, 2ft.-4ft. ..	1-3
Trimmers; shavers; saws	1-3
Baling machines	2
Conveyors	5
Paper presses	3
Farm Machinery—	
Ploughs	30-60
Threshers, light	5-10
heavy	20-40
Cake mills, small	1-2
heavy type ..	5-10
Clover huller	12-24
Root cutter	¼-1
Chaff cutter	2-5
Bone mill	1-3
Milking machine; separator; churn	½-1
Irrigation pumps	10-20
Service pumps	½-5
Cement Machinery—	
Roller mills	10-20
Tube mills	50-150
Double tube mills	100-250
Concrete mixers *per cub. yd./hr.*	½-¾

Machine	H.P.
Flour Mills, etc.—	
Combination cleaning machine	1-3
Stone grinders, 2ft. stone .	5-10
4ft. ,,	10-25
3 pr. roller mill, 500-2000 lb. per hr.	5-25
Dough kneading *per sack/hr.*	2
Light mixing machines ..	½-1
Weighers and cutters ..	1-3
Colliery Machinery—	
Winders	50-2000
Haulages	15-150
Conveyors	10-25
Coal cutters	15-30
Percussion drills—	
short stroke	1-2½
high power	5-10
Screens; washers	15-150
Air compressors	20-100
Cranes and Lifts—	
Travelling crane, 5-20 tons—	
Hoist	10
Travel	3-5
Traverse	1-3
Lifts, 30ft./min. ½ ton ..	3-5
1-2 tons .	6-20
Express passenger ..	25-35
Laundry—	
Small mangle or washer	½
Washers, 50-200 shirts ..	1-3
Wringers, ironers	1-2
Hydro-extractors	2-5
Decoudun ironer	1-3
Roller ironer and drier ..	2-5
Miscellaneous—	
Domestic purposes ..	$\frac{1}{16}$-¼
Corresponding hotel service	¼-1
Exhaust fans, 1000-3000 c.ft./min.	⅛-½
5000-10000 c.ft./min. ..	¾-1½
Refrigerator, 1-1½ tons ice/24 hrs.	5-7½
Riveting or countersink machines	3-4
Forge fans, *per fire* ..	½
Organ blower, *per* 10 *stops*	1
Paint mills	2-5
Bottle washers	1-3

with the useful work done, hence to reduce the costs per job the output must be increased, *i. e.* idle time must be eliminated from the cycle. Punches and shears consume more power during acceleration than during the working period; the requisite high starting torque may be obtained by a compound d.c. motor, by a slip-ring induction motor, or by a squirrel-cage motor with high-resistance end rings. The last-named motor is reliable and convenient for such service, and its speed decreasing with rising load makes it easy to use a flywheel. The use of a flywheel reduces current surges and mechanical stresses, but for best results the flywheel must be designed to suit the characteristics of the load and the speed characteristics of the motor. It is better to use a flywheel to deal with peak loads than to "over-motor" the machine and thus incur low power factor, reduced efficiency and higher capital charges. In many classes of industrial load the mean power is 25 to 50 per cent. of the peak h.p., and if the latter is to be carried without a flywheel, the motor must be larger than required by the mean load. This involves several per cent. extra on the power bill and, in the case of induction motors, a serious reduction in power factor; induction motors lose 2 or 3 per cent. in efficiency and 10 to 15 per cent. in power factor on reducing the load from full to half.

Motor Horse-power.—It is mistaken policy to install motors of much higher horse-power than is required by the load (or than will be required at a very early date), under the impression that this is "liberal design" and calculated to improve reliability. Any modern motor of good make is as reliable at its rated load as it is at partial load, provided that the rating is in accordance with British Standard Rules. "Over-motoring" means needless investment and is particularly bad practice where a.c. motors are concerned, because the power factor, as well as the efficiency, is much reduced by running such motors below say 75 per cent. of their rated output. Tests in a certain large works showed the motors to be running under an average load equal to 30 per cent. of their rated capacity, the average power factor being 60 per cent. and the average motor efficiency 79 per cent.; by increasing the average load to 75 per cent. of the rated capacity, the power factor might be brought up to 80 per cent. or higher, and the efficiency up to 85 or 90 per cent.

Whenever practicable the *rating of motors* should be specified and tested in accordance with the British Standardisation Rules for Electrical Machinery, which are now published at 1*s*. net. A simple rule, useful as a general guide, but *not* to be considered as replacing the standard rules, is that motors for continuous service

should be capable of yielding the desired max. h.p. *for* 6 *hrs.* without rising more than 70° F. above atmospheric temperature for open or semi-enclosed motors, or more than 90° F. for totally enclosed machines; or *for* 1 *hr.* with the same temperature limits in the case of motors for intermittent service. So long as the output, temperature rise and conditions of test are specified fully, machines may be compared even though the basis of rating differs considerably. Any motor for industrial service should be able to deal with a reasonable overload indefinitely, but if there are severe peak loads a flywheel should be used if practical or else the machine should be driven as one of a suitable group. A motor to drive a single machine with very "peaky" load and no flywheel is costly.

A useful rule giving the *continuous* rating of a motor suitable for specified variable load service is : H.P. $= \sqrt{[A^2t_1 + B^2t_2 + \ldots.)/T]}$; where A, B, etc. = h.p. required for periods of t_1, t_2 etc. seconds; and T = total period of cyclic variation of load $= (t_1 + t_2 + \text{etc.} \ldots)$ seconds.

Operating Notes.—Judging by experience, it is not superfluous to point out that electric motors should be cleaned and lubricated regularly. There are many cases in which motors run for months at a time with practically no attention, but it is only fair to inspect them and, if necessary, wipe them down (preferably removing dust from the windings by suction cleaner) and replenish the oil in the bearings at least once a week. As a matter of fact it pays to inspect running motors, and do anything that may be necessary, every two or three hours.

Overheating of a motor may be due to mere mechanical overload, or it may be caused by the temperature of the surrounding atmosphere being abnormally high (*e. g.* rolling mill motors). Overheating is very likely to occur if an "open type" or ventilated motor is boxed in or located in a very small chamber with inadequate ventilation. It is very easy to place a motor under practically "enclosed" conditions without realising this fact and the fact that the safe output of the motor has been correspondingly reduced.

The correct location of a motor in the first place is a factor of great importance. Apart from convenience and efficiency in driving the load, it should be remembered that a motor on the floor often occupies valuable space and is exposed to falling dirt, oil, etc. On the other hand, a motor mounted on the ceiling may be exposed to excessive heat and moisture, and is necessarily more or less inaccessible. A motor mounted suitably on the machine itself or on a wall bracket often avoids the above disadvantages.

Lack of balance, indicated by vibration or, in the case of induction motors, by bumping of the rotor on the stator,

may be dynamic lack of balance or electrical or magnetic lack of balance, *e.g.* eccentric gap, unequal current in phases, open circuit or defective contact in phases. Lack of balance due to defective design is difficult to cure; the remedy for other causes is obvious. Play in the bearings due to wear or mechanical slackness leads to trouble if there is out of balance pull.

The air gap of an efficient induction motor is very small, and if the rotor fouls the stator the consequences are abrasion, high friction, and finally breakdown. The heat caused initially by friction is accentuated by that due to frictional overload. The best means of avoiding this trouble is to use ball or roller bearings. On no account should the rotor be turned down to increase the air gap; this would reduce the attention required by the bearings, but would incidentally ruin the characteristics of the machine. Material increase in the load on an induction motor causes overheating, and so does low voltage, which (by reducing the torque proportionally to V^2) necessitates considerable increase in current to maintain output. Other possible causes of heating are high voltage, low frequency, unbalanced voltage, or the running of a polyphase motor as a single phase machine. If one slip ring of a wound-rotor machine be mounted directly on the shaft and the neutral of the star connected starting resistance be also earthed, one phase of the resistance is shorted, hence the other phases are badly overloaded (by 70 per cent. voltage increase) and the machine is started very violently. Grooves are sometimes formed on the front and back of carbon brushes, especially in traction service. Current flow has nothing to do with this effect; the grooving is due merely to particles of grit working down between the brush and its holder.

In the interests of continuity of service, an adequate stock of motor spares and spare fuses should be kept in store and labelled clearly; the use of a standard line of motors reduces the number of spares required. Insulation troubles in traction motors, and others exposed to dirt and moisture, are reduced by periodic dipping and baking. On being withdrawn from service, the machine is cleaned thoroughly and the armature and field system are dried in a steam oven and then dipped in a suitable insulating varnish which is subsequently baked. All air should be expelled from the coils during dipping; the parts should be drained for some hours before baking, and the commutator and other contact surfaces should be washed with petrol before baking.

Armature Faults in d.c. machines may be "earths," short circuits or open circuits. Short- and open-circuit faults may be partial or complete. Breakage in the armature circuit (generally at commutator lugs or connecting leads) is specially frequent in

reversing machines. The armature core must be tight and rigid and the commutator leads supported as necessary. The tests described below need a P.O. type galvanometer and a few storage cells capable of yielding a medium current; the actual number of cells depends on the armature resistance and on its normal rated current; a variable resistance permits the current to be regulated.

Open Circuit.—(a) *In commutator connections.*—Open the field circuit, lower brushes, connect cells through ammeter to brushes. Rotate armature one segment at a time, and the ammeter reading will be smaller or zero when the commutator bar with faulty connection comes under a brush. The brushes should not be wider than the commutator segments for this test; also, the commutator must be clean and the resistance of external circuit constant during the test. (b) *In armature coil.*—Test with field open, brushes lowered, cells connected to brushes, and galvanometer between adjacent bars in turn. Little or no current flows through the half of the armature containing the damaged coil, hence the galvanometer shows little or no deflection until it bridges the bars connected to the faulty coil.

Short Circuit.—Test with field open, cells connected to brushes and latter lowered, galvanometer connected to adjacent bars in turn. (a) *Shorted commutator bars.*—The voltage drop in successive coils (and hence the galvanometer deflection) is the same until the shorted bars are reached. The deflection then decreases or becomes zero according to the completeness of the "short." (b) *Shorted armature coils.*—By spanning three bars instead of two, as in (a), twice the former pressure drop is indicated until the faulty coils are spanned. The deflection is then reduced.

Earth Faults.—Method 1: Test with field open, cells connected to lowered brushes, galvanometer between frame and each commutator segment in turn. The deflection decreases as the tapping lead of the galvanometer approaches the earthed bar and is finally nil. The connection between bar and coil must be opened to decide whether the "earth" is on the bar or the coil. Method 2: Test with field winding connected to galvanometer, one brush raised, cells between frame and other brush. Electromagnetic induction causes galvanometer deflection when the battery key is closed, and the brush rocker should be set so that the deflection is a maximum. The armature is then rotated and the test repeated with each bar in turn below the brush. The deflection is zero or a minimum when that bar is reached which is earthed.

Emergency Service.—Spare motors of 5, 10, 15 or 25 h.p., according to the nature of the installation, are useful for emer-

gency service at times of breakdown or overload. The reserve motor may be mounted on a wheeled truck or on skids for ease of transport, and it may be spragged or bolted in position to drive a split pulley at any convenient point in the transmission system or, in the case of overload, certain machines may be detached from the original drive and driven independently from the reserve motor. The latter may be supplied through C.T.S. cables on cleats, and the driving belt should be protected by lattice screens or wooden slats. The truck or sledge carrying the motor should also carry the motor starter and a stepped pulley on a short shaft coupled to the motor.

In emergency a series wound motor may be adapted to constant speed service by connecting the field coils across the mains in series, with such resistance that the field current is rather less than its full-load value (when operating as a series machine). A variable resistance connected in series with the armature provides speed control. This arrangement involves considerable losses, hence proper shunt field coils should be provided at the earliest opportunity.

Three-phase induction motors may be operated on single-phase supply by connecting the third lead of each machine to an auxiliary line to which also is connected the third lead of a "master motor," the latter being a squirrel-cage or slip-ring induction motor connected to the 1 ph. supply and to the auxiliary line. The master motor should be of at least twice the rating of the largest "power motor," and the larger it is, the better. The voltage induced in the third phase of the master motor feeds the auxiliary line and permits the power motors to operate with practically the same starting torque and with 75 or 80 per cent. of the output obtainable by operation on 3 ph. supply. The master motor must not carry more than 25 per cent. (preferably less) of its rated mechanical load. It is started as a split-phase machine. As regards efficiency, the losses in the master motor practically balance the gain in efficiency by three-phase operation of the power motors.

Changing Motor Voltage.—When possible the maker's advice should be asked as to the advisability of the change and the extent to which it will affect the various components of the equipment. For the same h.p. on lower voltage the current-carrying capacity must be increased if the voltage is to be raised the questions of insulation and commutation are important. Larger cables and brushes are generally needed where the current is increased consequent upon reducing the voltage. If it is difficult to accommodate larger brushes, copper brushes may solve the problem if the machine runs in one direction only and under fairly constant load. Copper brushes cause

more commutator wear and need more frequent attention. Halving the voltage of a d.c. motor usually means a new armature winding and connecting the shunt field coils in parallel instead of in series. The field regulator and wiring must be capable of carrying the heavier total field current, and the series field coils of compound motors must be paralleled or series-paralleled.

Fig. 15A illustrates a simple method of changing the end connections of a 440 v., 2 ph., 4-pole motor so as to double the number of paths through the armature and adapt the machine for operation on 220 v. supply. The converted connections in the A phase (the B phase being similar) are :— X_1 to beginning of A_1

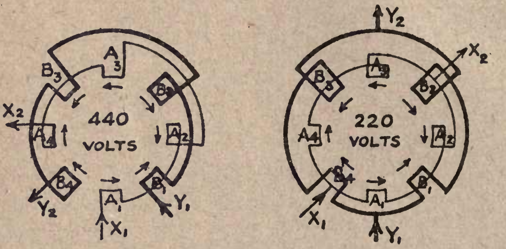


FIG. 15A.

and end of A_4; X_2 to beginning of A_2 and end of A_3; beginnings of A_3 and A_4; ends of A_1 and A_2. The impedance of the parallel circuits is unequal if the bearing be worn, resulting in eccentric air gap. Unequal current distribution due to this cause may be prevented, if the number of pairs of poles be even, by connecting diametrically opposite coils.

THE USE OF FLY-WHEELS WITH ELECTRIC MOTORS.

A ROTATING fly-wheel is essentially a reservoir of energy. As such it may be used to maintain nearly constant speed by absorbing or providing temporary differences between driving and resisting torques; or it may be used to relieve the driving agent of load in excess of a predetermined amount during periods of temporary overload. A gas engine fly-wheel is an example of the former application. As used with electric motors the main aim

of fly-wheels is not to preserve uniform speed (this result can be obtained by choosing a suitable type of motor), but to equalize the load on the motor or on the supply mains. A fly-wheel—properly selected and applied to a motor serving a load which consists of intermittent heavy demands with intermediate periods of light load—permits the motor to run on a practically steady load equal to the average of the actual fluctuating demand. With the aid of a fly-wheel, the motor may supply peak demands equal to several times its rated horse-power; and the average efficiency is raised.

The fly-wheel does *not* add energy to the system (on the contrary there are considerable friction and windage losses in the case of a heavy, high speed wheel). It acts only as a reservoir storing energy during periods of light load for use during periods of heavy load. If the fly-wheel be coupled mechanically to the load it equalises the demand on the motor, and permits the use of a smaller motor than would otherwise be required. Alternatively the fly-wheel may be coupled to an auxiliary generator working in parallel with the supply mains. The latter are then relieved of peak loads; peak demands are supplied by the auxiliary generator, but the driving motor is not then relieved of the peak loads.

The energy stored in a fly-wheel varies with the square of the angular speed; and in order that energy may be stored, and subsequently yielded up, the wheel must be capable of increasing in speed during light-load and decreasing in speed during heavy-load periods. The actual speed variation depends on the energy to be stored or returned, and on the inertia of the fly-wheel. The greater the permissible speed variation, the lighter the fly-wheel may be for given energy interchange or balancing effect. Obviously it is useless to fit a fly-wheel to a constant speed motor. The motor must have a speed characteristic which droops with increasing load. The actual speed variations under any particular load fluctuations can then be kept as narrow as desired by using a fly-wheel of greater inertia.

Fly-wheels are used very successfully with electric motors driving punches, shears, rolling mills, colliery winding gear and so on. They are useless with synchronous a.c. motors and of very little use with such nearly constant speed machines as d.c. shunt and squirrel cage a.c. motors. On the other hand a fly-wheel is useful with d.c. compound motors (cumulative series turns); with d.c. shunt motors having automatic field control (the field being strengthened as the load increases); and with a.c. induction motors having wound rotors and "slip" regulators (which should be controlled automatically by the load variation).

In the latter case the slip may be controlled by liquid or grid type resistance, but in large sets it is worth using an a.c. commutator motor to regulate the slip; this auxiliary machine adds its output to that of the main motor, or drives an auxiliary generator returning energy to the mains. The speed of series motors decreases with load, but generally too considerably to permit fly-wheels to be used satisfactorily; also the tendency to race on light load makes the series motor unsafe for service in which a certain minimum load is not maintained.

Suppose that a motor and fly-wheel has been running light for long enough to attain maximum speed. On the occurrence of a load, power may be drawn at once from both motor and fly-wheel; but it is often better to maintain the motor speed until full rated output of the motor is reached, and then to draw upon the fly-wheel for demands in excess of the rated output. Otherwise much of the energy stored in the fly-wheel is withdrawn before the motor is fully loaded, and there is so much the smaller reserve for use beyond the full load output of the motor. Generally a fly-wheel is of most benefit where load fluctuations are severe and fairly rapid.

In heavy industrial applications of fly-wheel storage (*e.g.* rolling mills and colliery winding gear) there are used fly-wheels weighing many tons and running at the highest safe speed, so that weight is a minimum for given storage. Cast-steel wheels may run at peripheral speeds from 23,000 to 17,000 ft. per min. according to size; and armour-plate wheels at 25,000 ft. per min. Wheels from 5 to 15 ft. diameter, weighing 5 to 30 tons, are used in fly-wheel storage sets for colliery winding. The following formulæ, etc., are given by the General Electric Mining Bulletin. The size of motor follows directly from the load diagram knowing the overload capacity of the machine and the main h.p. required. The average input during the cycle is obtained by adding the instantaneous losses to the load curve. Loads in excess of this average are supplied by the fly-wheel. Taking the period for which the fly-wheel output is a maximum :—Weight of fly-wheel (in lbs.) $= 35{,}400 \times$ fly-wheel output (in h.p secs.)$/(V^2 - v^2)$: the maximum and minimum velocities (V,v) being measured at the radius of gyration, *i.e.* at $0{\cdot}707 \times$ rim radius in the case of disc wheels. To estimate bearing friction assume coefficient of friction $= 0{\cdot}004$; windage loss (in h.p.) for smooth uncased wheels $= 0{\cdot}0513\ V^{2{\cdot}5} \times 0{\cdot}093D^2(1 + {\cdot}465B^2)/10^5$; where $V =$ peripheral ft. per sec.; $D =$ wheel diam., ft.; $B =$ wheel width, ft.

The closer a fly-wheel is placed to the point of variable power demand, the smaller the portion of the system affected by peak loads. For instance, a fly-wheel on the crank-shaft of a punching machine smooths out the load peaks almost at their source;

whilst if the fly-wheel be on the motor shaft the peak loads are transmitted through the driving gears. Similarly if a rolling mill motor be fed from a fly-wheel storage motor-generator set the peak loads are operative back to the generator of the balancer set and the balancing is only as regards demands on the supply mains. On the other hand, it may be preferable to use a relatively light fly-wheel on a high speed motor- or counter- shaft rather than the much heavier wheel needed on a slow speed shaft to produce the same balancing effect. If so, the transmission between the high and low speed shafts must be designed to withstand the load peaks. In the interests of capital economy, fly-wheels storage sets should deal only with surplus energy demands on peak load. If the whole energy supply passes through the balancer set, the component machines of the latter must be of practically the same rating as the main motor.

CARE OF COMMUTATORS AND BRUSHES.

A DAMAGED commutator cannot be "run in" by continuing it in service. It and its brushes must be put in good order; then, if all is well, they will remain so and the commutator will develop a healthy glaze. Defects in either commutator or brushes will generally produce defects in the other, and unless the initial cause and damage be removed, sparking is cumulative. For causes of sparking *see* "Dynamo and Motor Defects."

Bad contact in the brush holder and loose or inadequate connection of brush tails cause resistance loss (often fluctuating); overheating and perhaps sparking occurs at the point of bad contact. Brush chattering and sparking may be caused by unsuitable design of brush holders and arms; incorrect spring adjustment; or high micas. Brush holders and springs should be adjusted as required by the wear of brushes and / or commutator. The nature and degree of adjustment vary with the mechanical details of the brush gear. The main points are, that the peripheral spacing of the brushes should be equal; that the brush setting gives minimum sparking; that the bearing pressure is correct (measure by spring balance); and that the bars are in uniformly good condition and do not wear in grooves. A current density of 40 to 60 amps. per sq. in. may be allowed in carbon brushes; and 100 amps. per sq. in. in copper brushes.

The bearing pressure per sq. in. of carbon brushes on the commutator may be 1 to 2 lbs. in stationary motors and dynamos, and 3 to 6 lbs. where there is much vibration tending to cause chattering.

Commutator "dressings" should be used with great discrimination. If the commutator develops a healthy brown gloss where carbon brushes are employed, there is nothing to be gained by applying lubricant. A *mere trace* of vaseline or oil helps to maintain the glaze and will often silence screeching. Serious screeching is generally accompanied by heating and wear, and is due to hard or gritty brushes or excessive brush pressure. Best results are generally secured from that grade of carbon which needs no appreciable dressing. Dressing applied to a commutator stays there or on the brush gear and collects dust and particles of carbon and copper; this leads to risk of short circuit. A relatively heavy dressing of graphite and vaseline may be valuable on the commutator of a low voltage plating dynamo working with heavy copper brushes, whereas a tenth of the same dressing on a 200–600 v. motor would cause furious sparking, flash-over and short circuit. Wherever a dressing is used, the brush edges, brush holders and the commutator (particularly the slots if the micas be undercut) must be kept clean.

It is often recommended that carbon brushes be boiled in refined paraffin wax. Generally a *trace* of vaseline or oil on the commutator is equally satisfactory, easier to apply, and less likely to cause fouling. Boiling carbon brushes in thin mineral machine oil and then allowing them to drain thoroughly is also an effective treatment.

For copper brushes a lubricant often recommended is paraffin oil 5, olive oil 3, and ammonia 2 parts. The use of copper brushes is now practically confined to heavy current machines such as plating dynamos. A paste of vaseline with finest graphite, melted and worked well into the brush tips, and the same paste used as a commutator dressing, is very satisfactory for such machines. Finest electrotyping plumbago is generally available where plating dynamos are concerned, but other grades of graphite would serve if fine enough to penetrate well into the gauze brush. Clogging and collection of dust due to surplus vaseline must be avoided. If two sets of brushes be provided, the spare set can be cleaned, trimmed and dressed at leisure. The brush holders should be kept clean. This system of lubrication is only suitable for low voltage machines, up to 10 or 12 volts.

After some weeks of service, a commutator running beneath carbon brushes should develop a rich brownish glaze, which is

dead smooth and resembles a lacquered finish. Thereafter wear on the brushes is very slight, and on the commutator is practically nil. A black or dull brown surface on the commutator generally means that the brushes are too soft; and that they will wear rapidly, introduce risk of flash-over, and cause short circuit between bars if the micas be undercut. Raw copper on the commutator surface indicates abrasive brushes and possibly excessive brush pressure as well.

Commutator flats and pitting can be removed only by reducing the whole commutator surface to the level of the bottom of the flat or pit. Damage partially removed soon becomes as bad as ever. Persistently recurring flats may be due to defective metal in the bar; to brush chatter; or to some electrical defective in the machine windings. If micas are left projecting above the bars ("high micas"), brush chatter is caused and this results in sparking, brush wear, and the formation of flats. Abrasive brushes may keep the micas level; or the relative difference in wear between copper and mica may remain, and in either case commutator heating and wear will be increased. Undercutting micas by a milling cutter or piece of hack-saw in a suitable holder is effective, but forms a potential trap for oil and dirt. Micas should not be undercut if it is not certain that the grooves can be kept clean in service.

Pitted mica may be due to spots electrically or mechanically weak; to breaking of part of a high mica; or to a heavy curren-splash. To prevent local accumulation of more or less conducting dirt, the whole length of the mica may be undercut if considered desirable, or the pit may be cleaned out and filled with a suitable insulating material. A stiff paste may be used of powdered mica with water glass; plaster of Paris with insulating varnish; or powdered mica with shellac varnish. Air bubbles should not be left in the stopping.

If sparking occurs on the bearing face of a carbon brush rather than at the edges it may be due to imperfect bedding; to lack of uniformity in brush material or structure; or to the current being too heavy for the brush material or section. Overheating occurs and the face of the brush is made porous and friable. A better grade of brush of higher conductivity or a larger brush section per spindle should be used.

With copper brushes, judgment is needed in setting the back and front clamping plates to yield the best degree of flexibility in the brush tip. If the end of the brush be cut off square about $\frac{1}{8}$ to $\frac{1}{4}$ in. from the tip after bevelling, there is left at the back of the bevelled part, a body of gauze which gives mechanical support; also this method of trimming helps to prevent the formation

of a ragged "fringe." Carbon brushes are held either normal or nearly normal to the commutator by holders which do not permit of much change in the brush angle. Copper brushes are set at a small angle to the tangent to the commutator, and differences in brush stiffness, length unsupported, and strength of springs, cause unequal wear, and hence cause the brush spacing to become unequal. This results in sparking whether there is one or more brushes per spindle.

A true cylindrical surface is essential to sparkless operation of an ordinary commutator. To remove severe damage it may be necessary to turn the surface in a lathe or to use a suitable turning or grinding attachment mounted on a brush arm. It is risky to use a file or hand turning tool. Copper is apt to tear if turned unskilfully; chips must not be left embedded in the mica. Formerly commutators were turned frequently and an inch or more of spare depth was provided to allow for this. Suitable carbon brushes cause very slight wear; re-turning should rarely be necessary; and there is little margin of depth in the commutator bars to allow for it. Slight damage may be removed, and a "finish" given by glass-paper (*not* emery) mounted inside a broad block of wood shaped to the commutator radius. Glass-paper held in the hand merely perpetuates (if not aggravates) flats, etc. A commutator stone, used skilfully, cuts down high micas satisfactorily, but the shaped wooden block or a grinding attachment is generally safer.

TRANSFORMATION OF CURRENTS.

Whilst low pressure current is needed for domestic and many industrial purposes, high pressure current is more economical for transmission purposes. The principal reason for the increasing popularity of a.c. is that it can be generated easily at high pressures and transformed statically to higher pressure for long distance transmission and to medium or low pressure at the point of utilisation. In many cases d.c. supply is essential (e.g. for accumulator equipment and electro-chemical work in general) or preferred (e.g. for traction and variable speed motor drives). Transformation of currents both as regards pressure and kind is an important operation and the following are appliances used for the purpose :—*Converting A.C. to D.C.*—(1) Synchronous motor generators. (2) Asynchronous motor generators. (3) Rotary converters. (4) Motor converters. (5) Rectifiers. *Converting High Pressure to Low Pressure Current and vice versa.* (1) Motor dynamos for D.C. (2) Static transformers for A.C.

MOTOR GENERATORS.

A motor generator set is a combination of motor and generator whose shafts are generally direct-coupled, the whole being supported upon one bed-plate. When current at a given pressure is supplied to the motor, electrical power is converted into mechanical power, which in its turn is utilised to drive the generator from which current at a desired pressure is obtained. If the motor be an alternating current one, and the generator be a continuous current machine, it is clear that alternating currents will be transformed into continuous currents.

A synchronous motor-generator consists of a synchronous motor and a continuous current dynamo, and the following are the characteristic features of this combination :—

The synchronous motor possesses no starting torque, and a small auxiliary (induction) motor is required to get the synchronous motor up to its proper speed, when it is synchronised with the supply circuit. An exciter is also required for the field magnets of the motor, unless there is a battery of accumulators always available for excitation purposes. The speed of the synchronous motor is constant for all loads, and the generator portion can only be put on after the motor has been properly synchronised. The generator may be shunt wound, compounded or over-compounded, and in this way the continuous current voltage can be regulated for variations of load like an ordinary generator. By over-excitation of the motor the power-factor of the supply circuit may be made unity; increasing the excitation further still will make the supply current lead upon the supply pressure. The synchronous motor may be connected directly to high-pressure mains without using transformers.

An asynchronous motor-generator consists of an induction motor and a continuous current generator; it is self-starting, but its speed varies slightly with different loads. There is perfect freedom as regards the regulation of the continuous current pressure with varying loads, and with respect to the ratio between the alternating and continuous current pressures, as is also the case with the synchronous motor generator. No exciter or continuous current supply is required for the motor, and the controlling mechanism is of the simplest type.

Motor generators for changing continuous current pressures are but seldom required, and these consist (1) of two continuous current machines—one a motor and the other a generator—whose armatures are designed to work at different pressures; or (2) a double-wound armature, arranged to rotate in a common field and with two commutators.

ROTARY CONVERTERS.

Types and Uses.—The rotary converter consists essentially of a d.c. dynamo with the addition of slip rings at the opposite end of the shaft to the commutator. In a 1 ph. converter there are two slip rings connected to diametrically opposite points in the armature winding. In a 2 ph. converter there are four slip rings connected to the armature at 90° points so that *either* 2 ph. 4-wire supply may be fed into the armature and d.c. be taken from the commutator brush gear *or* d.c. may be fed in by the latter and 2ph. (4-wire) made available at the slip rings. In a 3 ph. converter there are three slip rings connected to 120° points in the armature and in a 6 ph. converter there are three pairs of rings connected to three pairs of diametrically opposite points in the armature winding, 120 (electrical) degrees apart. There are generally certain distinctions between a modern rotary converter and d.c. dynamo, the speed of the former being higher, the brush gear designed to suit the speed, and the commutating poles designed to suit the special armature reaction. These distinctions are not, however, radical differences of principle. A "rotary" is generally self-exciting from its d.c. terminals, but there are modified methods for special control purposes. If a rotary converter be driven independently and excited from its commutator (or from an independent source of d.c.), it forms a double-current generator yielding both d.c. and a.c. As generally used, it runs as a synchronous A.C. or as a shunt wound D.C. motor and supplies D.C. or A.C. respectively from its "generator" terminals.

The principal present day applications of rotaries are to converting a.c. supply to d.c. for traction purposes; for power station d.c. auxiliaries and miscellaneous d.c. supply; for electrolytic work and battery charging. The importance of rotary converters is great and increasing, for they are reliable, efficient machines capable of being built in large units; turbo-alternators are the standard generating units in practically every new power plant in this country and a certain amount of d.c. power is and will continue to be needed. Rotaries fall off in efficiency and rating if the armature current be of less than unity power factor. If used for power factor correction, these machines are more costly and less efficient than normal rotaries.

Single phase rotaries are inefficient, costly and involve operating difficulties. A motor-generator is preferable for converting 1 ph. a.c. to d.c. The present notes refer to polyphase con-converters unless otherwise stated. A rotary converter yields uniform d.c. voltage, whereas the d.c. voltage and current curves of a rectifier are intermittent with half-wave and undulating with whole-wave rectification.

Characteristics and Rating.—The rotary converter is cheaper and more efficient than the motor-generator, there being one machine instead of two. Using a single armature winding for the double purpose of *polyphase* a.c. motor and d.c. generator (or d.c. motor and *polyphase* generator) causes more or less "cancellation" of current in parts of the winding. This results in reduced reactions and reduced heating, and permits higher rating. So far as the heating limit is concerned, the *relative output* from the same machine in various services is : As d.c. generator :—1·0; as converter:—1 ph., 0·85; 3 ph., 1·34; 4 ph., 1·64; 6 ph., 1·97; 12 ph., 2·24. The rating of a given carcase is greater, the greater the number of phases. These figures assume unity power factor. On 0·8 p.f., the ratings are : 1 ph., 0·62; 3 ph., 0·87; 4 ph., 1·0; 6 ph., 1·12. *Typical efficiency data* are, at full, $\frac{3}{4}$ and $\frac{1}{2}$ load respectively : Rotary converter and transformer (overall) 94, 92, 91%. La Cour converter, 92, 91, 90%. Motor generator 87, 86, 83%. Large mercury rectifier 88 to 90, 86$\frac{1}{2}$ to 88$\frac{1}{2}$, 85 to 87%.

Standard rating limits for 25, 40, 50 and 60 cycle rotaries are 50 to 3500 kw., 1500 to 250 r.p.m., 440 to 600 v.; also 220 to 300v. up to 1000 kw. Machines giving 1200 to 1500 v. d.c. may be used singly or two in series on heavy traction, 25 cycle service. For higher frequencies use two 600 to 750 v. machines in series, *or* a motor generator set with two generators in series for over 1200 to 1500 v. The increased peripheral speed of commutator in modern rotaries reduces the risk of flash-over. A heavier and more effective damping winding (and hence less risk of hunting) is possible in high speed machines because of the greater space available with fewer poles. The saving in cost due to fewer poles for given frequency at higher speed is partly offset by the cost of longer commutator to collect current and the more costly construction for equal commutator safety. The overload capacity of modern high speed rotaries is greater than that of older, slower types. The precise speed of any rotary varies with the specified temperature rise, power factor and overload capacity, and to some extent with the d.c. voltage. The speed of Siemens' 50 cycle converters for 440 v. and upwards is 1500 r.p.m. up to 200 kw.; 600 r.p.m. from 1200 to 1500 kw.; and 333, 300 and 250 r.p.m. for 3000 kw. and larger sets.

A damping winding of copper rods through the pole faces, joined to short circuiting rings at each end to form a squirrel cage winding, may be used to damp-out *hunting*. Where the load is very variable (e.g. traction service), the damping winding should not form a closed circuit round the commutating poles. The old prejudice against 50 cycle converters is no longer justified. Due to commutating poles and higher speed (resulting in greater

peripheral distance between $+^{ve}$ and $-^{ve}$ d.c. brushes), operation is stable and there is freedom from flash-over. *Commutation* in a modern rotary on reasonably steady load, is in fact, better than in a d.c. generator, hence the *overload capacity* is high. For most purposes it is quite sufficient if the converter (after continuous full load for 6 hrs. or more) will carry 25% overload for 2 hrs.; 50% overload for $\frac{1}{4}$ hr.; or 100% overload for 1 minute. In railway service, heavily built converters are often used, with 50% overload capacity for 2 hrs., and 200% momentarily.

Voltage Ratio and Voltage Control.—More or less inflexibility in voltage control forms the principal drawback to rotary converters. Whereas the e.m.f. of a motor generator does not depend on the supply pressure, but can be regulated and compounded at will, the pressure ratio (d.c. : a.c.) of a double-current armature moving inside one set of field magnets is a fixed ratio. A step down transformer is needed on the a.c. side of a converter fed from a high tension a.c. system. Thanks to various recent improvements, a satisfactory degree of compounding can be obtained in modern rotaries.

The definite ratio between a.c. and d.c. volts in a rotary converter is expressed by the equation, $E_a = \{E_c \sin(\pi/n)\}/\sqrt{2}$; where E_a = a.c., e.m.f. between rings; E_c = d.c., e.m.f.; n = number of slips rings. The commutator voltage is the peak value of the e.m.f. wave in the armature and the slip ring voltage is the R.M.S. value. With diametral connection of each transformer phase, the ratio of a.c. : d.c. volts is theoretically 0·707 for 1, 4 and 6 ph. rotaries (and is actually between 0·71 and 0·76, owing to the wave not being truly sinusoidal). In 3 ph. and 6 6 ph. double delta rotaries the ratio is theoretically 0·612 and actually about 0·634.

Though *voltage control* is not an inherent property of the rotary converter it can be made wider than generally supposed. The degree of regulation specified should, however, be as small as possible (and based on the working values of a.c. and d.c. pressure) because wide voltage control increases the cost and reduces the efficiency of the machine. The *methods available* are by—(1) Field regulation using series reactance. (2) Induction regulator. (3) Synchronous a.c. booster. (4) Varying shape of flux wave by splitting each pole into two parts, one excited at constant, and the other at variable pressure. The first three methods all depend upon raising the a.c. voltage applied to the slip rings of the converter.

(1) *Reactance Control.* In order to obtain the characteristics of a compound wound d.c. generator series field turns may be connected as usual in the d.c. side of the machine, (in addition to the shunt winding connected across the d.c. brushes); in addition,

there is a suitable reactance connected between the a.c. line and the slip rings. Increase in the d.c. load then strengthens the field, and this means that the converter is running as an over-excited synchronous motor, and therefore takes a leading current. The series reactance when traversed by leading current produces a rise in the a.c. pressure on the slip rings. The voltage ratio of the converter between slip rings and commutator being fixed, the desired rise in d.c. pressure is obtained. Over-excitation might be obtained with the same result by regulating the shunt field. Unfortunately reactance control of converter voltage produces a wattless current in the armature and an uneven distribution of heating which reduces the rating. It is only practicable to obtain say $\pm 7\frac{1}{2}\%$ (15% total) voltage regulation by this means.

(2) *Control by Induction Regulator.* The induction regulator consists of a boosting transformer constructed like an induction motor, so that the linkage of the secondary winding with primary flux can be varied by altering the setting of the rotor. The amount of "boost" is thus under control, and the slip ring voltage may be raised without reducing the p.f. (as with reactance control). The converter field must be varied as required to maintain balance between the generated and applied e.m.fs.

Control by Synchronous A.C. Booster. The principle is exactly the same as in the previous case, but instead of using a boosting transformer, the a.c. pressure applied to the converter slip rings is varied by a small synchronous generator mounted on the converter shaft and connected in series with the a.c. supply.

Choice of Voltage Control.—Reactance regulation involves departure from unity p.f. and necessitates costly increase in size of machine for given rating. Voltage regulation by boosting disturbs neutralisation of the armature reaction and necessitates special arrangement to get good commutation; it is possible to get $\pm$ 15% regulation by boosting, but it is better not to specify more than $\pm 12\frac{1}{2}\%$ variation (25% total). *Four cases* may be considered, viz. (1) Constant, high tension a.c. pressure and d.c. variation not exceeding 15% or total range of both a.c. and d.c. pressure not exceeding 15%. Induction regulator generally too expensive. A.C. booster often cheaper than reactance control. (2) Same as case (1), but constant p.f. required. Use induction regulator or booster. The latter makes possible unity p.f., whether the machine be shunt or compound wound. (3) High tension a.c. pressure variation up to 10% *and* 15% d.c. variation. An induction regulator or booster is essential to deal economically with this range of regulation. (4) Reversible running required, or d.c. to a.c. only; other conditions as under (1), (2), or (3). A booster or induction regulator is essential, *unless* the converter runs in parallel with a synchronous machine able to supply the wattless component needed to give the desired voltage control when using the reactance method.

Starting Rotary Converters.—When d.c. supply is available (e.g. from storage cells), the simplest method of starting is to start the converter as a d.c. motor and then synchronise it on the a.c. side, preferably on the h.t. side of the transformer because of the lighter switchgear then to be handled. *Starting from the a.c. side* introduces some complexity because a synchronous motor is not self-starting. The converter may be started *either* by an auxiliary motor *or* as a squirrel-cage motor fed at reduced voltage from tappings on the transformer. The auxiliary motor may be electrically independent of the main machine which it simply brings up to speed ready for synchronising in the ordinary way. Generally, however, a self-synchronising auxiliary is now used with its stator windings in series with the converter slip rings. In order to start by tappings, the field circuit is opened at one point (preferably several points). About $\frac{1}{3}$ full a.c. pressure is applied and the machine starts as an induction motor, the damping winding acting as squirrel-cage stator. When the machine is up to full asynchronous speed, the field circuit is closed and the armature then pulls into step. Full A.C. pressure may be reached safely by two stages. The starting current is heavy (full load value), but soon decreases as the machine gathers speed. The starting current is much lower when using an auxiliary motor.

Parallel Running.—The virtual absence of armature reactance makes the voltage characteristic of a rotary converter very flat, so that if the machine is to be paralleled with a d.c. shunt generator, *reverse* series turns must be provided on the converter field so as to increase the pressure drop on increasing load.

Inverted Running.—Any rotary converter may be used to yield a.c. from d.c. supply. The chief difficulty encountered when so using an ordinary rotary, is that variations in a.c. power factor cause variations in armature demagnetising effect, and hence variations in the net field and in the speed of the converter (which is being driven as shunt or compound d.c. motor). The ultimate effect of p.f. variation is therefore variation in converter speed and frequency. Siemens' method of overcoming this difficulty is to give the main excitation of the rotary from the commutator as usual and to take auxiliary excitation from the commutator of an auxiliary armature fed through slip rings from a series transformer in the a.c. circuit. The field of the auxiliary exciter is due simply to the armature reaction of the transformer secondary current and it (and hence the auxiliary excitation of the converter) varies with the p.f. of the a.c. load. The auxiliary commutator operates at very low voltage. Should the auxiliary excitation fail, the main excitation still prevents the converter from racing. Finally, speed and frequency variation are *prevented,* not merely corrected.

MOTOR CONVERTERS.

The motor converter, or, as it is more correctly called on the Continent and in America, the cascade converter, was patented by Messrs J. L. la Cour and O. S. Bragstad in the year 1902, and the British manufacturing rights were subsequently secured by Messrs. Bruce, Peebles & Co. Ltd., of Edinburgh. It consists of an ordinary induction motor with wound rotor, and a direct-current machine, rigidly coupled together on a common bed-plate. The rotor and armature are, in addition, connected electrically, as shown in Fig. **16**. For the sake of simplicity, it may be assumed that the motor and converter have the same number of poles—in the case shown in the diagram, two poles—and, deferring for the moment the question of starting, it may be assumed that rotor

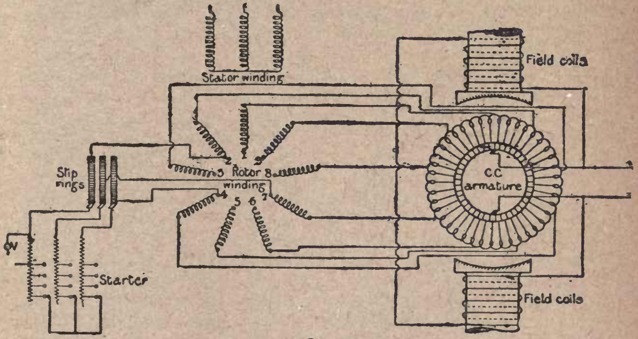


FIG. 16.

and armature are running at a speed corresponding to half the primary frequency. In other words, the rotor is running with 50 per cent. slip. Therefore the revolving field induced in the rotor by the primary circuit rotates, relatively to the rotor, at a speed corresponding to half the frequency of the supply circuit, and it thus induces in the rotor windings a series of e.m.fs. which have also half the frequency of the supply circuit. Now the number of poles of the continuous-current machine is so arranged that the frequency of the currents induced in the armature winding at the given speed is the same as the frequency of the rotor current. For this reason it is possible to connect the rotor and armature windings together when their e.m.fs. are equal and in phase, and when this is done the speed remains constant, and the two machines connected in tandem behave as a single synchronous machine.

As the induction motor rotates at a speed corresponding to half the primary frequency, half the electrical energy supplied to the induction motor will be converted into mechanical energy and transmitted by means of the shaft to the converter, while the other half of the energy supplied is transferred to the rotor winding and thereby to the converter armature in the form of electrical energy; thus the induction motor operates half as motor and half as transformer, while the converter operates half as continuous current generator and half as rotary converter. As the rating of the induction motor depends on the speed of the rotating field, and not on that of the rotor, it is theoretically half as large as if, with the given number of revolutions, it were to convert the whole of the energy led in into mechanical energy. The converter runs at a speed equal to half the primary frequency, which is more advantageous with regard to commutation, consequently it is made of smaller proportions than an ordinary continuous current generator or converter for the same output and primary frequency. The rotor of the induction motor is usually constructed with twelve phases, as the losses of conversion are then reduced to a minimum.

A motor converter may be started up from the high-tension side in the same manner as an ordinary induction motor. Alternating current at the supply pressure is connected direct to the stator windings, and three of the twelve-phase windings of the rotor are connected through slip-rings to an external non-inductive resistance, which is gradually cut out until the direct-current machine excites and the set reaches synchronous speed, when the slip-rings, and with them the whole twelve rotor windings, are short-circuited. The direct-current machine may then be paralleled with the bus-bars in the ordinary way. Starting up from the direct-current side is effected in the ordinary manner by means of a direct-current starter, and when the set has reached synchronous speed, the high-tension side is synchronised with the alternating current mains.

The motor converter can be used for three-wire supply; the outer mains are then connected as usual to the positive and negative terminals, whilst the middle wire is connected to the star-point of the rotor windings, and may be earthed. A motor converter, thus connected up, automatically balances the current, and the voltage difference between the two halves is well within one-half per cent. of the voltage between the outers, with an out-of-balance current of 20 per cent. of the full-load current. If it should be necessary to keep the voltage of the two sides of the system absolutely equal, or even raise the voltage of the heavier loaded half to compensate for the extra drop in that side in feeders and distributing cables, a booster must be put in circuit. Such a booster is series wound, and can be driven by the extended converter shaft.

RECTIFIERS.

There are quite a number of ways by which one or both sets of half-waves in a.c. supply can be utilised as intermittent or undulating d.c. Most of the known methods are used in practice according to the pressure and volume of current concerned. Naturally a single rectifying device passes current in one direction only, so that, unless its connections be reversed synchronously with the reversals of the a.c., both alternations of the latter can be utilised only by connecting four rectifiers, so that two pass current in one direction and two in the other; the rectified current can then be arranged to flow always in the same direction through the external circuit. Undulating rectified current may be equalised to a great extent by inductance. Heating varies with C^2 and is greater than produced by a steady current of the same *mean* value, but it is the mean current which is effective in electrolytic work, accumulator charging etc. Oscillograms are a great help in developing the design and ascertaining the performance of any rectifier.

Mechanical Rectifiers.—The principle employed is that of reversing the connections between a.c. and d.c. circuits at the moment when the a.c. reverses its direction. This is accomplished by a synchronously vibrating, contact-making " reed " armature in the *vibrating rectifier*, which is useful for charging small batteries. The *permutator*, which is suitable for higher power, uses synchronously rotating brushes or commutator instead of a vibrating contact arm. A machine of this type marketed for charging ignition batteries consists of a small synchronous motor with an extended shaft on which are mounted slip rings, fed by a.c. and connected to the commutator from which d.c. is collected. The chief trouble with mechanical rectifiers is the sparking which inevitably accompanies reversal when current and pressure are not exactly in phase.

Electrolytic Rectifiers.—One form consists of an aluminium and a lead or steel container as electrodes with ammonium phosphate as electrolyte. Current can pass from the electrolyte to the Al, but not in the reverse direction, owing to a polarisation film of aluminium hydroxide. The latter is of remarkable dielectric strength ($>$ 100 v. for a film of molecular thickness), and may be used as dielectric for a condenser by using two sets of Al electrodes close together. Low current density at the rectifier cathode reduces the risk of polarisation there. About 135 v. per Al-rectifier cell is recommended for efficiency. The secondary volts decrease with load, which is a useful feature in cell

charging but bad for lighting service. The usual limits of output are 100 watts to 10 kw. Internal losses are due partly to leakage, partly to pressure drop. Efficiency decreases rapidly with rising temperature, especially above 50° C., and is about 3% lower at 200 than at 40 cycles. Efficiency of a certain 500 w. rectifier = 60% at 6% full load; 73% at full load; and 70% at $2\frac{1}{4} \times$ full load. A full load efficiency exceeding 75% is obtainable under favourable circumstances.

Fig. 17 represents an arrangement used to obtain up to 0·01 amp. d.c. at pressures up to 10,000 v. for test and experimental purposes. Alternating current from a source G is taken through a variable resistance R to a transformer T, the ratio of which may be varied. High tension a.c. is thus applied to a "bridge" circuit of condensers K_1K_2 and two sets of electrolytic cells connected in opposite directions and each containing 70 cells in series. There are no wearing or moving parts and the d.c. terminals are "dead" until the a.c. supply is switched on. The rectifier units consist of test-tubes containing $NaHCO_3$ solution as electrolyte and *Al* and *Fe* wires as electrodes.

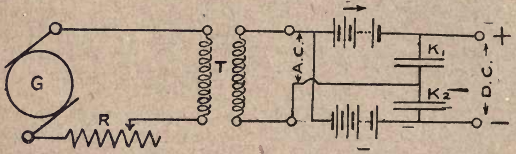


FIG. 17.

Cup and Point Rectifiers.—Cup and point electrodes have a very powerful rectifying effect on a.c. applied to them. This action is due to the peculiar distribution of electrostatic stress and is particularly useful for very high pressures. **Crystal Rectifiers.**—Unilateral conductivity in certain crystals is a property of practical utility in some cases, but only where very small currents are concerned. **Vacuum Rectifiers.**—A vacuum tube with one hot and one cold electrode acts as a rectifier, current being carried by negative electrons from the hot electrode (an incandescent filament). The *kenotron* is a rectifier of this type and is useful in wireless telegraphy, etc.; the current carrying capacity is very small and the pressure drop between anode and cathode is some hundreds of volts. This rectifier is suitable only for high pressures (up to 180,000 volts or over).

"Tungar" Rectifiers.—A rectifier of this type consists of a glass bulb filled with argon at low pressure and provided with a heavy carbon block as anode and a spiral of tungsten wire (kept incandescent by A.C. taken through a transformer) as cathode. The argon is ionised by discharge from the incandescent filament, and provides a path of unilateral conductivity, current flowing only from the carbon to the incandescent filament. Two half-wave rectifiers may be connected so as to utilise the whole a.c. wave. Full-wave rectifiers are being developed. Tungar rectifiers will carry several amperes with a pressure drop of 5 or 10 v., and are therefore suitable for charging small batteries and operating small electrically driven apparatus; they are self-starting and almost instantaneously so. The life of the bulb is at least 800 hrs. and is often 1000, 2000 or even 3000 hrs. This is a useful rectifier for anything from $\frac{1}{2}$ kw. d.c. (up to 75 v. or so) down to a small fraction of 1 amp. Three patterns are available at present: (*a*) 2 amp. rectifier taking 60 to 80 watts from 115 v., 60 ~ supply, and charging 3, 6 or 8 cells at 2, 1 or $\frac{3}{4}$ amp. respectively; (*b*) $7\frac{1}{2}$ to 15 v. rectifier, charging 3 or 6 cells at 6 amps.; 45% efficiency on full output of 90 watts; (*c*) $7\frac{1}{2}$ to 75 v. rectifier, for 3 to 30 cells at 1 to 6 amps.; 75% efficiency on full output of 450 watts.

Arc Rectifiers.—It is the stream of particles from the *negative* electrode which makes possible the maintenance of an arc between whatever electrodes. If one electrode be water-cooled (hollow copper construction is convenient), current will flow in the direction for which the cool electrode is $+^{ve}$, but not in the opposite direction (e.g. from cold copper to carbon but not *vice versa*). When such an arc is fed with a.c., current does not flow during one half wave of e.m.f., but there is enough hot vapour between the electrodes to re-form the arc when the e.m.f. reverses. If a third (auxiliary) electrode be inserted in the vapour column of a d.c. arc, it assumes the potential of the $-^{ve}$ electrode; a.c. supply connected to the positive and auxiliary electrode can send current only from the former to the latter.

Mercury Vapour Rectifiers.—These depend upon the fact that 20 v. or so will send current from $+^{ve}$ to $-^{ve}$ through the vapour column of a Hg arc, whereas the vapour column is practically non-conducting in the opposite direction. For outputs up to 5 or 10 kw. one or two Hg rectifiers with glass bulbs may be employed; "ironclad" rectifiers with steel containers, work on the same principle and have been built experimentally up to 1200 kw. The glass bulb type comprises a small bottom chamber

for the Hg cathode and above this a large chamber for condensing Hg vapour. There are two or three side tubes (1 or 3 phase) containing carbon anodes; these tubes may be of L–shape to reduce risk of short circuit when working with high pressures. The construction of the ironclad type is essentially the same; water cooling with thermo-circulation is provided; special care is needed to secure air-tight insulating bushes for the anodes, but it is possible to run the latest ironclad rectifiers without a vacuum pump once the container is thoroughly exhausted. The Hg rectifier is likely to come into more extensive use as a.c. supply becomes more common. It is cheap and simple in comparison with rotary converter equipment; and has high efficiency (85 to 90%). Two or more rectifiers can be used satisfactorily in parallel. There is possibility of obtaining a.c. of variable frequency from d.c. supply by inverting the action of mercury rectifiers.

The rectifying arc may be struck by hand or automatic tipping gear from an auxiliary Hg electrode, near the cathode and connected to an anode through suitable resistance. Alternatively, a solenoid-operated "striking" electrode or an auxiliary h.t. discharge may be used. Reactances smooth the wave form of rectified current, and prevent extinction of the arc whilst the a.c. e.m.f. passes through zero. Artificial cooling is needed except in small power, medium pressure apparatus; water or oil cooling is preferable to air blast. A.C. supply to the anodes is through a static transformer yielding the secondary voltage V_{ac} corresponding to the desired d.c. pressure V_{dc}. For *single phase* rectifiers: $V_{ac} = 2{\cdot}4\ (V_{dc}^{ac} + 15)$ volts. For *three phase* rectifiers: $V_{ac} = 1{\cdot}6\ (V_{dc} + 15)$ volts. Voltage control up to $\pm$ 5% may be obtained by tappings on the supply transformer, or wider range may be obtained by induction regulator or step transformer; choking coils with adjustable cores give simple and flexible voltage control for battery charging. The voltage drop from half to full load was about 10% with 25 cycles supply, and nearly 30% with 100 cycles supply, in the case of a certain 1 kw. rectifier with glass bulb. The regulation of ironclad rectifiers can be made anything from 5% up to 15 or 20% according to the characteristics of the source with which they are to be paralleled; or by suitable size and arrangement of inductances, constant d.c. volts may be maintained over a wide range of load. Total loss in the supply transformer decreases with frequency down to 40 cycles, and increases rapidly below 30 cycles; loss in the bulb itself is roughly twice as great at 100 as at 25 cycles supply frequency. The frequency of pulsation of the rectified current is twice the frequency of the a.c. supply.

Small Hg Rectifiers are used charging small storage cells, supplying cinematograph arcs and so forth. A typical *battery charging* equipment for stationary service, comprises a rectifier tube, regulating compensator, switch panel, main reactance and a.c. series reactance; and yields d.c. at from 5 to 40 volts from 110 v., a.c. supply. A convenient *portable rectifier* for use in charging car-lighting batteries *in situ* yields 5 amps. at 7 or 15 v. and is suitable for charging one or two 3-cell or one 6-cell battery from 110 v. a.c. supply at 25 to 133 cycles. The rectifier bulb is only 4″ diam. and the complete equipment in ventilated case measures 12″ × 10″ × 9″ and weighs 18 lbs. For supplying *projector arcs*, etc., it is convenient to use the largest size of glass-bulb rectifier, viz. for 30, 40 or 50 amps. d.c. output. For cinematograph arcs it is generally necessary to use two such rectifiers in parallel and, since the characteristics of the bulbs are never identical, a compensating transformer is placed in circuit to reduce the p.d. across which neither lamp tends to be overloaded.

High Power "Ironclad" Hg Rectifiers. The first Hg rectifier with steel container was built in the U.S.A. in 1909 for 80 kw. d.c. output. Modern units now in service in Continental substations and industrial installations, etc., are built with 6 to 12 anodes carrying 50, 100, or 200 amps. each and the maximum cathode current is 250 or 500 amps. at 110 to 800 volts. The largest units standardised for industrial service yield 500 amps. d.c. at 750 volts, and five such in parallel yield 1875 kw. Large Hg rectifiers will supply 100% overload momentarily. A 100 kw. 3 ph. rectifier measures about $4\frac{1}{4} \times 7 \times 6\frac{1}{2}$ ft. overall, the main chamber being $3\frac{1}{4}$ ft. high × $1\frac{1}{2}$ ft. diam. An efficiency of 90% is obtainable on full load (300 amps., 350 v.), and 86% at $2\frac{1}{2}$ kw. ($\frac{1}{40}$ full load). After the first few weeks or months, continuous operation of a vacuum pump is not necessary to maintain the vacuum. Good results have been obtained with experimental units for outputs up to 1000 to 1200 kw., 600 to 1400 amps. By devoting special attention to the arrangement and insulation of anodes and the collection of condensed Hg, so as to reduce risk of short circuit, high voltage rectifiers have been operated satisfactorily up to 6 amps. d.c. at 20,000 v. In the near future 1000 kw. Hg rectifier substations are likely to be common, and possibly stations with 1000 kw. units. As high voltage Hg rectifiers are perfected, the overall efficiency will probably exceed 97% and it will be possible to convert a.c. to d.c. in 1000 kw. or larger static units as efficiently as we now change the pressure of a.c. by static transformers.

A Mercury Rectifier Locomotive tested on the Pennsylvania Railroad consisted of a motor car with 11,000/1,200 v. static trans-

former; a 1 ph. Hg rectifier; and 4 d.c. motors, 1000 h.p. total. The transformer had tappings placed symmetrically on each side of the secondary mid-point, and yielding zero to maximum a.c. volts. The cylindrical steel casing of the rectifier measured 20″ diam. × 36″ high. A small motor generator set struck the arc; the main motor inductance was sufficient in the d.c. circuit. The motors were permanently in series-parallel; maximum d.c. pressure to earth = 600 v. Loss due to 25 v. drop in rectifier = 18¾ kw. at full load (750 amps. d.c.). During the trials the loco ran 240 mls./ day for months on end with very satisfactory results, combining the merits of d.c. traction with those of a.c. power transmission.

Data Required for Hg Rectifiers. Particulars to be specified when inquiring for Hg rectifiers are: *A.C.*—Frequency; pressure and pressure fluctuation. *D.C.*—Service in view; pressure and pressure regulation; min., mean and max. amps. required. If for battery charging state make, type and number of cells; number in series; a.hr.— capacity; min., mean and max. charging amps.; volts/cell, charged and discharged; whether battery is to float continuously on the rectifier.

STATIC TRANSFORMERS.

A static transformer changes the pressure of an alternating current (and changes the amperage in inverse ratio), without the use of any moving parts. If a.c. be passed through an insulated winding round a closed magnetic circuit, an alternating flux is induced in the latter and this flux induces an alternating E.M.F. in a second insulated winding on the same core. The flux also induces a back-E.M.F. in the primary winding = Supply voltage — CR, where C denotes the primary current and R the equivalent ohmic resistance of the winding. The magneto-motive force (M.M.F.) of the secondary winding is opposed to that of the primary, so that as the secondary load increases the primary current also increases automatically. According to the relative number of turns in the two windings, the transformer is "step-up" or "step-down" as regards primary : secondary voltage, the voltage ratio being practically equal to the ratio of the corresponding number of turns. *Transformer Losses.*—The principal losses are those in the windings (copper loss) and those in the core (iron loss); in addition there is the loss due to magnetic leakage (part of the primary flux does not pass through the secondary windings). *Copper Losses* range from 1 to 5% of the output and vary with the square of the current carried and with the resistance of the winding. *Iron Losses* vary from 1½ to 5% of the output and consist of eddy and hysteresis losses.

Eddy losses vary with the square of the plate thickness, of the frequency, and of the maximum flux density. High resistance in the core material increases the loss due to stated current flow, but (which is more important) reduces the current corresponding to a given E.M.F. Hysteresis losses vary with the 1·6th power of the maximum flux density; with the frequency and form factor of the magnetising wave; with the composition and quality of iron, its mechanical treatment, and working temperature.

In order to increase the resistance to circulation of eddy currents the core is built up from laminations insulated from each other; the insulation between laminæ occupies about 10 per cent. of the overall volume of the core. The net flux through the core, and hence the iron losses, are practically constant at all loads. Temperature rise reduces the core loss but increases the copper loss. In a range of transformers of similar type but different capacities, the weights and losses vary roughly with the $\frac{3}{4}$ power of the rated output. *Typical efficiencies* of transformers at full load (and quarter-load) respectively are as follows, for various ratings: 5 kw., 97% full load (94·5% at $\frac{1}{4}$ load); 50 kw., 98·3% (97·2%); 100 kw., 96·5% (93·5%); 500 kw., 97·8% (95·6%); 2500 kw., 4% (96·5%).

The *all-day efficiency* of a transformer is an important factor and is given by the ratio Output/Input taken over 24 hrs. or over such less part of the day as *the primary of the transformer is in circuit.* The energy consumption for ventilation or water circulation should be reckoned as part of the "input." Low iron loss is particularly desirable in transformers which are excited continuously but supply a (secondary) load only intermittently. Conversely, low copper loss is specially important where the load factor is high. Many old transformers have poor "all day" efficiency and it would pay to scrap them in favour of transformers using improved methods and materials of construction. Heating due to high iron loss is wasteful in itself and leads to further loss by increasing the resistance of the copper. The higher the temperature, the greater the risk of insulation troubles.

Voltage Regulation.—The actual secondary voltage of any transformer is less than the theoretical value owing to magnetic leakage and ohmic loss in windings. The voltage "regulation" of the transformer is defined as the percentage increase in secondary voltage when the load is reduced from full to zero (the primary voltage being constant). Regulation is less close as the power factor decreases.

Constructional Types.—Two windings on a core made up of superposed rings of sheet iron constitutes a transformer which

has some good points but is costly to make and is rarely employed. The closest practical approximation to "ring" construction consists of four sets of rectangular plates (Fig. 18, I) either "butting" together or interleaved to form a "sandwich joint." Tight clamping reduces magnetic leakage and prevents vibration and humming. Magnetic leakage is further reduced by winding the secondary outside the primary coil and by placing such a

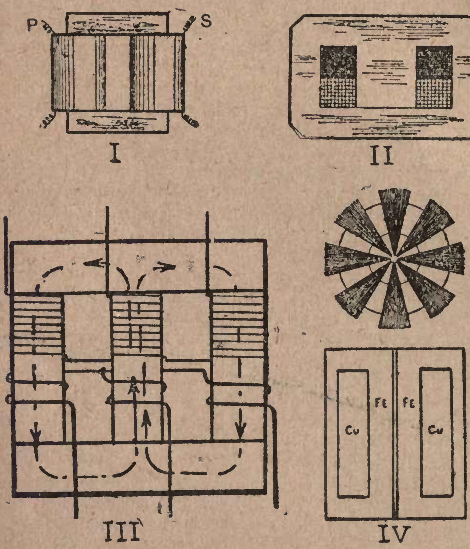


Fig. 18.

pair of windings on each leg of a 3-limb core (Fig. 18, III), a 3 phase transformer is obtained. The 3 ph. coils may be connected in star or delta (Figs. 19, I and II); or a star primary may be used with a delta secondary. The mesh connection (Fig. 19, II) permits two transformers to maintain supply should the third be incapacitated; if full output be still required, the two transformers in service are overloaded by 16%. In a 3 ph., 4-wire system the primary windings are star connected and the secondaries delta connected. This sytem has the advantage

that lighting, heating and power can be supplied from one circuit, single phase transformers being connected between phase wire and neutral and the latter being earthed. The 4-wire, 3 ph. system is analogous to the 3-wire d.c. system of distribution and the size of wire for a 4-wire system is one-third that for 3-wire distribution with the same load and pressure drop. If two 1 ph. 2300 v. circuits be combined to form a 2300/4000 v., 3 ph., 4-wire circuit, the capacity of the latter is three times that of the two 1 ph. circuits.

In Fig. 18, I, the windings surround a single magnetic circuit and the transformer is of the "core type"; in Fig. 18, II, a

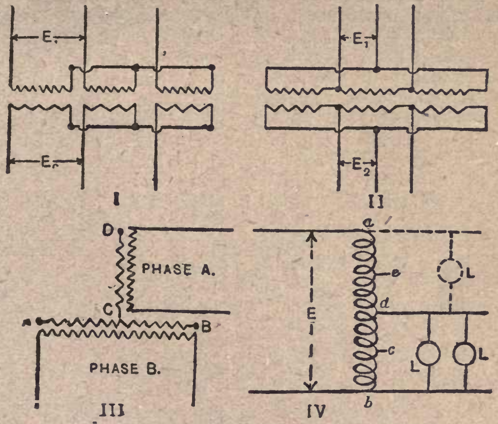


FIG. 19.

double magnetic circuit surrounds the windings and the transformer is of the "shell type." The Berry "ironclad" transformer (Fig. 18, IV) is a combined core and shell pattern. Shell type transformers have good cooling facilities and low magnetic leakage, but are subject to considerable risk of insulation breakdown and are therefore not to be recommended for high voltages.

Cooling.—Insulating materials deteriorate and iron "ages" if exposed to temperatures of 75° C. or higher; taking this as the absolute limit, the working temperature should not exceed 50° or 40° C. above atmosphere. With constant magnetic and

current density the rating of a transformer increases with the 4th; the weight and losses with the 3rd; and the radiating surface with the 2nd power of the linear dimensions, so that a limit is soon reached beyond which natural ventilation is inadequate. Forced ventilation by air blast may then suffice, but oil immersion is more effective and serves to insulate as well as cool the transformer. Radiating gills may be provided outside the containing tank, or water-circulating pipes may be added to cool the oil. If the water rate be high, it may pay to provide a small cooling tower so that a limited volume of water may be circulated continuously through a bank of large transformers. It is essential that the oil be dry since the smallest trace of moisture leads to insulation breakdown. Thermal and chemical drying processes are used, and special multiple filters with absorbent screens give satisfactory results. Various tank cover constructions have been designed to prevent ingress of water either as such or in the form of moist air drawn in by thermal "breathing" action. An oil which forms "sludge" in service is to be avoided, since sludge impedes cooling and favours insulation breakdown. Important researches have lately been conducted under the auspices of the I.E.E. concerning the qualities of transformer oils.

A suitable allowance of oil is about 6 lbs. per kva. output; and of water is {0·011 to 0·018 × Total loss (watts)/Temperature rise (° C.)}, the result being in galls. per min. Water tube diameters range from $1\frac{3}{16}$ to $1\frac{3}{8}$ ins., and 0·3 to 1 sq. in. tube surface may be allowed per watt dissipated. Dilute acid is useful in removing scale from tubes, but none must be allowed to get into the tank itself. The radiating surface of the tank should be $4\frac{1}{2}$ to 8 sq. in. per watt of loss. No part of the core should be more than 1 in. from the oil and the clearance between tank and transformer should be at least 6 ins. In h.t. transformers it may be necessary to lengthen the core limbs to provide sufficient clearance between h.t. coils and yoke; and supplementary insulation is desirable on the "end turns" (*i. e.* the last 100 ft. or so of the windings) to allow for local strain due to voltage surges.

Special Transformers.—This heading includes auto-transformers; constant current transformers; pressure regulating and "boosting" transformers; phase transformers; and instrument and bell transformers. An *auto-transformer* has a single winding with 3 or more tappings, the p.d. between which varies with the number of turns between tappings. The supply voltage may be raised or lowered; in Fig. 19, IV, the lamps L are supplied at E/2 volts. The high and low voltage circuits are not electrically distinct (as they are where double wound transformers are used).

Auto-transformers should not be used to connect distribution systems or disturbances will be transferred too freely from one to the other. The magnetic circuit of a double-wound transformer forms an "elastic" coupling which reduces the severity of transferred disturbances.

Boosting transformers may be of fixed or variable ration. In the latter case a primary winding, shunted across the supply and mounted on a "rotor" capable of adjustment through an angle of 180°, induces a supplementary E.M.F. in a secondary winding which is wound on the "stator" and connected in series with the supply. By the Scott "Tee-connection" of transformers, 3 phase current may be converted to 2 phase or *vice versa*; in Fig. 19, III, C is at the centre of AB. When the turn CD = 86·7% of the turns AB, balanced 3 ph. current is provided at ABD when 2 ph. current is supplied to phases A, B.

A *voltage stabiliser* recently placed on the market eliminates pressure variations in combined motor and lighting circuits, and consists essentially of a high reactance transformer. The motor current passes through the primary winding and the lighting circuit is in series with the secondary winding which produces "boost" varying with the motor current. Constant pressure is maintained automatically in the lamp circuit. *Constant current* transformers are used in series lighting circuits. The secondary winding is movable and is counterbalanced mechanically to such an extent that it is in equilibrium when supplying the desired steady current. Any change in the latter produces displacement of the secondary and such alteration in magnetic leakage that the current is brought back to normal value. *Instrument transformers* do not differ essentially from power transformers, but special care has to be exercised in order to obtain constant pressure ratio and avoid phase errors. Considerable space was devoted to *bell transformers* in the 1918 edition of this book. Light load current and energy consumption are more important than efficiency on load, since the total working period of bell transformers is only a few minutes per diem. An excellent core construction is to wind iron tape to form an ellipse of the desired section. Overheating is a common defect. The insulation should withstand 1000 v. indefinitely and 2000–3000 v. temporarily. From 0·1 to 0·5 amp. is generally sufficient in ordinary bell circuits of 4 to 30 ohms resistance. For domestic service, 5 to 10 v. is ample and the secondary output averages 1 to 5 watts. The efficiency may be from 60 to 75%.

MOTOR STARTERS AND CONTROLLERS.

Small d.c. and a.c. motors, such as series-wound fan motors of fractional horse-power and small squirrel-cage induction motors, may be started by switching straight on to the mains. The resistance of the windings on such small machines is relatively high and, owing to the small inertia of the rotor, acceleration is very rapid and the duration of the starting current is therefore small.

I.E.E. Rules.—The I.E.E. Wiring Rules require that all motors rated at more than $\frac{1}{3}$ h.p. be controlled by a double-pole switch and protected by a fuse or circuit-breaker on each pole (except with earthed concentric wiring, when no switch, fuse, or circuit-breaker may be placed in the external conductor). Also,

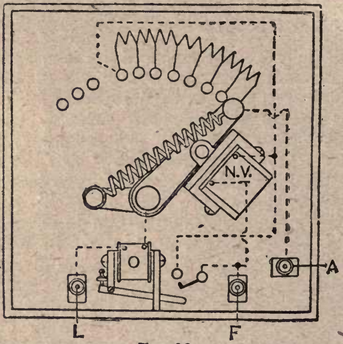


FIG. 20.

every d.c. motor must be fitted with a starting switch with no-volt release and series starting resistance; and every a.c. motor must be provided with a suitable starting device. The shunt circuit of a motor must be connected so that the field is excited before the armature circuit is completed, or alternatively the shunt circuit may be connected to the first step of the armature starting resistance.

Types of Starters.—*Rheostatic starters*, which insert a variable resistance in series with the motor, may be classified as follows: *Faceplate starters* in which the contacts are on a plane surface (Fig. 20). *Drum Starters* in which the contacts are on a cylindrical surface. *Multiple switch starters* in which the resistance sections are controlled by separate switches (suitably interlocked). *Solenoid-operated starters* in which (*a*) the lever of a faceplate starter is moved by means of a solenoid and core (Fig. 24); or (*b*)

the switches of a multiple-switch combination are operated by solenoids, the combination forming "contactors." *Liquid starters* in which the area of contact between electrodes and a suitable electrolyte is varied either by raising and lowering the electrodes or by varying the level of the electrolyte.

Compensator starters for 2 ph. and 3 ph. a.c. motors consist of an auto-transformer and switch so arranged that when the switch is in its intermediate position (or positions) reduced pressure is applied to the motor by the auto-transformer.

Switch starters for polyphase induction motors vary the connections of the stator phases during the starting period. For *three-phase* motors the stator phases are connected in tar during the starting period and in delta for normal running, by a *star-delta switch.* For *two-phase* motors the stator windings in each phase are connected in series for starting and in two equal circuits in parallel for normal running, by a *series-parallel switch.*

Faceplate Starters.—B.E.S.A. Report No. 82 gives the standard specification for faceplate starters for d.c. and polyphase a.c. induction motors with slip rings, not ordinarily requiring to be started more than twice per hour. The complete specification should be studied, but the more important points are given below, and it will be realised that many of these are equally applicable to other types of starters.

RATED PRESSURE. Standard rated pressures for d.c. motor starters are 110, 220, 440 and 500 v. No standards are given for a.c. rotor starters. D.C. starters must be suitable for starting a motor against a torque corresponding to its rated load on pressures differing from the rated pressure by not more than 10%. A.C. starters must be suitable for use on pressures differing from the starting pressure of the rotor by not more than 10%.

ENCLOSURE. An *open starter* is one with no cover over the front (whether the resistances are protected or not), and this type is not suitable if other than skilled attendants have access to it. In a *protected starter* the front has a cover with a slot through which the handle projects, and the resistances have a ventilated cover. In an *enclosed ventilated starter* the front is totally enclosed and the resistances have a ventilated cover. In a *totally enclosed starter* both the front and the resistances are completely enclosed by covers without openings and the starter is operated by a handle or wheel on a spindle projecting through the cover. A *drip-proof starter* has ventilating openings so protected as to exclude falling moisture or dirt. A *weather-proof starter* is a totally enclosed type with the joints of the covers so made as to exclude rain or moisture. *Flame-proof* and *submersible* starters are not recognised as standard types.

SIZES. The standard sizes are $\frac{1}{4}$, $\frac{1}{2}$, 1, 2, 3, 4, 5, $7\frac{1}{2}$, 10, $12\frac{1}{2}$, and 15 to 50 h.p. by steps of 5 h.p.

RATING. An *ordinary duty* starter is suitable when the time required to start from rest to full speed is not longer than 5 sec., plus $\frac{1}{2}$ sec. for each 1 h.p. of starter rating, the current peaks being limited to the values given below under "Normal Start." A *heavy duty* starter is suitable for use with punch presses, circular saws, and other loads having more than the usual amount of flywheel effect, but is not suitable for motors driving machines requiring more than 1 min. to start. The starting period for tests on heavy duty starters is 1 min.

Both ordinary and heavy duty starters must be uninjured by starting a motor (in the above-mentioned times and subject to the current limits specified under "Normal Start") five times in succession if the resistances are ventilated and three times if the resistances are totally enclosed, with an interval between successive starts = 15 × starting period.

NORMAL START. The normal start for ordinary duty and heavy duty starters is : (*a*) Current on first contact not more than $1\frac{1}{2}$ times full-load current for starters up to and including $7\frac{1}{2}$ h.p., and not more than full-load current for starters above $7\frac{1}{2}$ h.p.; (*b*) maximum current peak, when switching from contact to contact, not more than $1\frac{1}{2}$ times rated full-load current for d.c. motors. No current-peak limits are specified for a.c. motors.

[The starting current of a.c. motors varies considerably with the type and design of motor; the torque of the induction motor varies with the square of the voltage; the starting voltage applied must usually be at least 50% line voltage and the starting current is then about $1\frac{3}{4}$ times full-load current. Yet higher starting currents are common in practice.

Note.—In *drum starters* it is common for the current on the first contact to be $1\frac{1}{2}$ times full-load current up 10 h.p.; $1\frac{1}{4}$ times full-load current for 10–20 h.p.; and equal to full-load current for starters rated above 20 h.p. The current peak when moving from contact to contact may be somewhat higher than in faceplate starters, say twice rated full-load current.]

A table of values to be assumed for the *rated full-load current* of d.c. motors is given in B.E.S.A. Report No. 82; this table corresponds approximately to the formula :—

Full-load current D.C. Motors = K × H.P./Volts; where K is a factor having the following values :—

H.P.	K.	H.P.	K.
$\frac{1}{4}$	1360	15	873
$\frac{1}{2}$	1240	20	852
1	1145	25	840
2	990	30	836
3	953	35	830
4	935	40	830
5	929	45	824
10	880	50	824

The full-load current for a.c. starters must be determined from the motor characteristics.

CONSTRUCTIONAL FEATURES. *No combustible material* allowed in frames, supports, or case. With the exception of the external leads and the sockets into which they are soldered, all *electrical joints* are to be secured mechanically, whether soldered or not. Except the "off" and "full on" contacts, all *contacts renewable* from the front in starters above 10 h.p. for 110 v., or above 20 h.p. for 220 to 500 v. Starting-handle to move clockwise to increase the motor speed, and in d.c. starters a spring or other means must be provided to return the handle to "off" and prevent any part of the starting resistance from being left in circuit. *No-volt release* to be provided on each d.c. starter. *Overload release* need not be incorporated with d.c. or a.c. starters, but every motor circuit should be protected by independent fuses or overload cut outs. It should be impossible to disconnect the *field circuit* from the mains, by operating the starter handle, without a discharge path. An independent switch must be provided to break the main circuit of the motor; the starting switch should break the circuit only when it operates automatically. [*Note.*—This requirement is satisfied admirably by certain starters on the market in which all arcing on the contacts is prevented by arranging that the slightest backward movement of the starting-handle causes the main circuit to be opened at a separate circuit-breaking contactor.] Provision is to be made so that *conduit* (where used) can be attached securely to the starter case. *Temperature rise* of release coils as measured by thermometer not to exceed 50° C. *Terminals or sockets* are to accommodate cable of the size required by the I.E.E. Wiring Rules for the full-load current to be carried. Sockets to comply with B.E.S.A. Report No. 91. *Terminal markings* to be as follows: (*a*) D.C. Rheostatic Starters — Line, L; armature, A; field, F; resistance leads, R_1, R_2, R_3, etc. (*b*) A.C. Rheostatic Starters — Line, L_1, L_2, L_3; machine side, 3 ph. stator, A, B, C; machine side 2 ph. stator, A_0, A_1, B_0, B_1.

PRESSURE TESTS. To be applied only to new, completed starter in working condition and after 24 hrs. exposure to ordinary atmosphere. Test pressure (R.M.S.) to be applied for 1 min. between earth and the resistances and contacts, the starter frame being earthed during the test: Below 1 h.p. 500 v. plus twice rated pressure of starter. Starters of 1 h.p. or over, 1000 v. plus twice rated pressure of starter. Test pressure to be alternating, preferably sinusoidal; between 25 and 100 cycles per sec., and measured on the h.t. side of testing transformer. Initial test pressure to be one-third above value and increased to full-value as quickly as consistent with its value being indicated by the measuring instrument. Insulation resistance (measured at

500 v., d.c.) to be not less than 1 megohm when the pressure test is applied.

Constructional Data.—The following recommendations, etc., do not form part of the B.E.S.A. Specification, but may be found useful. Resistance coils should be of wire not smaller than 22 or larger than 10 S.W.G.; for heavier duty, strip metal, or flexible cast-iron grids are preferable. Liquid resistance or carbon plates interleaved with iron plates may be used. A useful resistance element consists of corrugated sheet metal, $\frac{3}{4}$ to 3 ins. wide, incorrodible, of high resistance and with low temperature coefficient. The strip is mounted on a centre spindle covered by micanite tube and with insulating bobbins between zigzags. This is suitable for heavy current; light; free from expansion and vibration troubles; and can be run at red heat, tapped anywhere and repaired easily. Large surface facilitates cooling, but ventilation is defective if centre rod be vertical.

Sectional area of resistance elements must be liberal where starting is frequent and acceleration load heavy. Sand, cement, or oil aids rapid heat dissipation. Relative value as heat radiator for given temperature above atmosphere: Dull iron 100; cast-iron 115; fine sand 130; oil 260. High-resistance elements may be made of wire wound on metal tubing (slotted brass for a.c.) insulated by vitreous enamel. The wire is covered by a paste of steatite, cæmentium, Portland cement, or fireclay, mixed with quartz sand and water; or of marble dust, litharge and glycerine. Newel insulating cement is fine clear sand 80; magnes. silicate 20; mixed with sod. silicate solution.

Springs should never be relied upon to carry current, and sliding surfaces should not carry more than 130 amps. per sq. in. No part of a starter should rise above 200° C. (392° F.); air-cooled resistances should be arranged so as to induce maximum ventilating draught; a protecting screen prevents short-circuit, shock, etc.

Gradation of Starting Resistance.—To attain perfectly uniform acceleration requires absolutely continuous variation of starting resistance; this is possible in liquid starters or screw-up carbon resistances, etc., but in wire rheostats the number of contacts is limited (to 6–12 in small and medium-sized starters), and the resistance between each is so chosen that, on moving from one stop to the next, the current does not rise above a predetermined limit depending upon the design and construction of the motor.

A neat graphical design for the resistance steps of a shunt motor starter is shown in Fig. 21. Lengths R_a, R_{ex}, along the base line represent the armature and total starting resistance to a convenient scale; on the vertical axis, current is represented in similar manner. $C = (C_{max.} + C_{min.})/2$ is the current which, if uniformly maintained, would give the uniform acceleration it is

sought to attain). Join OQ, drop PR perpendicular to AB; join OR, drop ST perpendicular to AB, and so on. The lengths r_1, r_2, r_3 . . . then represent, to the scale chosen, the resistances to be placed between the 1st and 2nd, 2nd and 3rd . . . starter contacts; also, these lengths are proportional to the times which

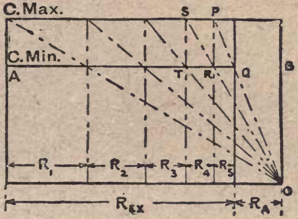


FIG. 21.

the handle should be held on the representative studs. The p.d. between adjacent contacts should never exceed 30–35 volts.

In designing compound and series motor starters, it is necessary to have the saturation curve of the machine in order that allowance may be made for the increase in field flux which occurs when the armature and series field current increases, due to the removal of a section of starting resistance. In these motors the back e.m.f.

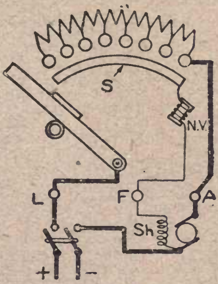


FIG. 22.

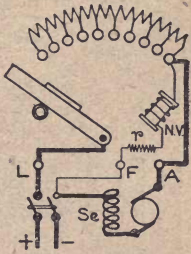


FIG. 22*a*.

rises at the moment of cutting out a resistance step *before* the armature speed rises; the grading of the resistance steps is quite different in starters designed for use with motors similar, except that they are respectively shunt, series and compound wound.

D.C. MOTOR STARTERS. Faceplate-type.—Various face-plate starters are illustrated by Figs. 20, 22*a*–23*a*, and 24–25. In all those for shunt motors special provision is made to ensure

full field on starting; this is secured automatically where series motors are concerned. Fig. 20 shows a common type of starter for shunt motors. If it be desired that full voltage be maintained

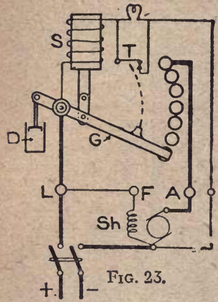


FIG. 23.

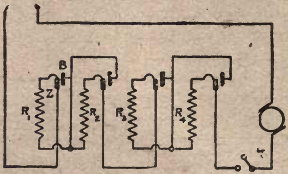


FIG. 23*a*.

on the field and hold-on circuit at all times (instead of the starting resistance being gradually inserted in the field circuit as is done in Fig. 20), this may be accomplished by adding a shunt contact strip S, Fig. 22.

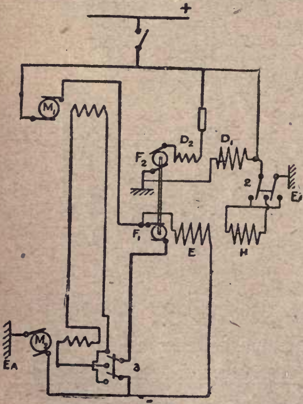


FIG. 24.

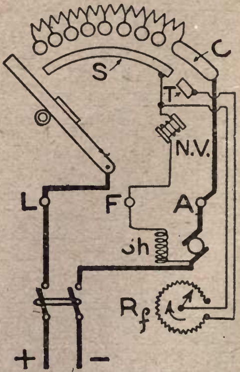


FIG. 24*a*.

The starter for a series motor may be practically identical with Fig. 20, except that the hold-on coil and field winding are in series with the armature. An alternative arrangement for a

series-motor starter is shown in Fig. 22*a*, the hold-on coil, in series with a suitable resistance, being shunted across the mains.

Hold-on Coil. The "no-volt" electromagnet NV, Fig. 20, holds the starting-handle "on" against the control of a powerful spring which pulls the arm "off" should supply fail or the field circuit be broken. The hold-on coil, constituting the no-volt release, may be connected in series with the shunt field (Fig. 20) or across the mains in series with a suitable resistance (Fig. 22*a*), a glow lamp often being used as this resistance. In the case of starters for series motors, the hold-on coil may be in series with the armature. If the hold-on coil retains the starting-handle after the circuit has been broken, the spring on the handle is probably too weak; on the other hand, if the coil will not hold the switch "on" during normal running there is probably a break in the hold-on circuit or a short-circuit fault in the winding of the coil, reducing its effective ampère-turns. In some cases dirt

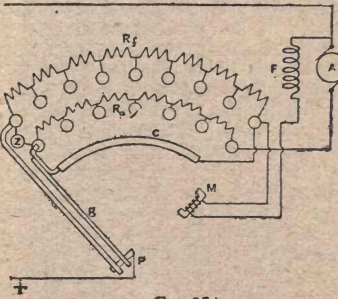


Fig. 25.

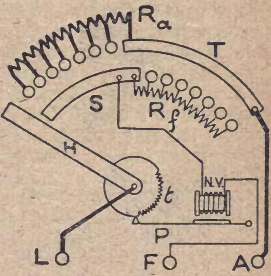


Fig. 25*a*.

or other foreign material prevents the armature from making good contact with the hold-on poles. The strength of the spring should not be reduced in order to allow a weak hold-on coil to hold the switch handle.

Overload protection should be provided by double-pole fuses or circuit breakers in the supply circuit. An auxiliary overload protection may be embodied in the starter, as in Fig. 20, an adjustable electromagnetic relay O short-circuiting the hold-on coil NV, and thus causing the starting-handle to be released, on the occurrence of a predetermined overload. Any one of several types of "time element" may be fitted to the overload release O to delay its operation and thus allow for temporary overloads without stopping the motor. A disadvantage of this overload protection (apart from some difficulty in setting accurately) is that the main current is broken over the starter contacts. An independent overload circuit-breaker is preferable, particularly for large motors.

Drum-type Starters.—The supply leads, motor windings and resistance sections are connected to a series of contact fingers which are arranged to press upon the circumference of cylindrical contact pieces mounted on a common spindle. The latter is rotated by the starting-handle, and the lengths, positions and interconnections of the contact pieces on the drum spindle are such that any desired sequence of connections is effected between the circuits connected to the contact fingers. A more complex sequence of connections can be effected by this than by any other type of starter, and there is no possibility of incorrect connections being made. Arcing shields are fitted between the contact fingers, and magnetic blow-out coils are also provided if the controller carries the main current. Where the current to be handled is very heavy, or where remote control is desired, the drum starter may serve simply as a master controller, controlling the excitation circuits of contactors in the main circuit.

Multiple Switch Starters.—These are electrically the same as faceplate starters, but a series of knife switches (mounted on a common spindle) is used to short-circuit the various sections of starting resistance. The switches have mechanical interlocking devices so that they cannot be closed in other than the correct sequence. The last switch (full-on) is provided with a hold-on coil which acts as no-volt release if the supply fails. Until the last switch is closed the attendant must hold in the last-closed switch, otherwise all the switches are opened by the springs with which they are fitted. This type of starter is often preferred instead of the faceplate type where heavy starting currents are concerned. In order to prevent the switches from being closed too rapidly, locking pins or triggers may be provided which make it impossible for any particular switch to be closed until the current has fallen to a predetermined value. Alternatively, as in certain faceplate starters, the switches may be actuated by turning a handle which drives through a large-ratio worm gear and thus imposes a (more or less indefinite) limit on the speed of operation.

Solenoid Operated Starters.—(*a*) *Faceplate type.* In the simplest pattern, closing the main double-pole switch excites the solenoid S, Fig. 23, and at the same time establishes full field in the motor. The solenoid core rises (under the control of the dash-pot D, which prevents too rapid removal of resistance) and cuts resistance out of the armature circuit. When the lever G reaches the full-on position it opens the tappet switch T, and thus inserts a lamp or other resistance in the solenoid circuit. The current through the solenoid is thus reduced to the value which suffices to hold the plunger in the " on " position. This value is considerably lower than the value required to start and operate the switch. By the use of the switch T the energy

consumption in the solenoid circuit is reduced. Where this type of starter is used, it is preferable to combine it with a solenoid-operated contactor in the main circuit. This contactor is closed and opened by push-buttons in its own circuit, and its function is to make and break the main current (preventing sparking on the faceplate contacts) and close the circuit of the starter solenoid. (*b*) *Contactor type.* Each contactor consists of an electromagnetically operated switch which cuts out of circuit one section of resistance. The contactors themselves are controlled by a hand-operated master controller of either the faceplate or drum type, or they may be controlled by any one of a number of types of automatic switch gear, with either time- or current-limit devices to control the rate of starting the main motor. Starting equipment of this type is naturally very suitable for high-power motors and for motors which operate under severe service conditions and/or are in charge of unskilled men.

Automatic Starters.—For small motors an automatic starter may be built on the hour-glass principle. Connection is established and resistance reduced between a centre rod and the metal container by carbon granules admitted from the upper chamber through an adjustable cone-valve. In the *variator* an enclosed iron resistance is heated, almost instantaneously, by the initial starting current to such a temperature that its resistance is about ten times its "cold" value. As the motor gains speed, the variator resistance decreases automatically and is finally short-circuited. Variators may be used conveniently for motors up to 8 h.p. A thermal auto-starter useful for small and medium motors utilises the thermal buckling of bi-metal strips to close contacts and short-circuit successively the starting-resistance sections (Fig. 23*a*).

Automatic starters and controllers for medium and high-power motors comprise master switches (operated manually or automatically by water floats, pressure diaphragms, etc.) and solenoid-operated contactors, or leaf-switches drawn over contacts placed in a straight line. An almost indefinite number of mechanical and electrical interlock systems and release devices are available according to the service to be rendered. Textbooks and the technical press should be consulted for details of these. *Time limit* action may be secured by dashpot or other mechanical means, or relays may be used to provide *current limit* action. The latter is the more rational in most cases. An automatic controller should prevent too rapid acceleration and too rapid electromagnetic braking. The master switch for any automatic starter or controller may be located at any convenient point. For machine-tool motors there are three classes of controllers all of which may be automatic in action (under the master control of button- or rotary-switches), viz.: Plain starters for constant-

speed motors; speed-setting controllers for variable-speed motors which run at constant speed during any particular job; speed-regulating controllers for starting and complete speed control. Press buttons for stopping motors may short-circuit the contactor solenoid or open its circuit; the master switch contacts are liable to be burned by inductive sparking in the latter case. The risk in the short-circuit method is that dirt may prevent short-circuit from being established directly the button is pressed; this risk is slight if the switch be well-built.

Liquid Starters.—*Advantages:* Smooth variation of resistance; cheap; simple; able to withstand rough usage. *Disadvantages* of old or inferior liquid controllers are messiness due to "creeping" of electrolyte; rapid deterioration; considerable attention required; trouble from gassing and heating. These defects are eliminated or reduced to unimportant proportions in the best modern apparatus, which is employed extensively in heavy industrial service. Liquid resistances are useful as variable rotor resistance when starting slip ring induction motors.

Electrolysis gives trouble with D.C. Current density not greater than 1 ampère per square inch; preferably 0·5 ampère per square inch; 0·7 ampère is good working density. Too high density leads to rapid destruction of electrodes, and gassing and vacillating resistance result. When whole resistance is cut out, a positive metallic short-circuit should be placed across the electrodes, either within the electrolyte or externally.

In mine winding and similar sets, the position of the starter plates may be controlled by a compressed air cylinder.

By splaying the plates, a better resistance gradient is obtained and the solution is mixed as the plates move. Small closely adjacent plates between the main plates practically short-circuit the starter when in the full-on position. In one type of liquid starter suitable for heavy power work (400–1500 h.p.) an electrically driven centrifugal pump circulates liquid continuously (during working hours) from a reservoir to an overhead electrode tank. The height of liquid in the latter and hence the resistance in circuit is determined by the position of a weir plate, movable under control of the operator. The maximum rate at which resistance can be removed from the motor circuit is determined by the setting of a valve in the pump delivery pipe. Cooling coils may be used to reduce evaporation of electrolyte. The lever controlling the weir plate may operate master switches controlling starting and reversing contactors. Automatic overload and no-voltage releases may be fitted.

For *ordinary motor starters*, etc., a salammoniac or common soda electrolyte is suitable; soda is cheaper and more satisfactory in other respects. Use 4 to 12 lb. crystals per gallon water and add fresh water as required by evaporation. Weak solution for

high resistance and low current density; strong solution for continuous heavy service. For *small work* use saturated copper sulphate solution and copper electrodes; this solution is non-polarising. A *non-freezing solution* is: water, 10 gallons; potash, 15 lb.; glycerine (30° Bé), 3 gallons. Correct composition from time to time as required. For *instrument circuits, testing*, etc., use a 10% solution of cadmium iodide in amyl alcohol. The resistance in megohms per cm. cube of other high-resistance liquids suitable for similar laboratory work are:—Ethylic alcohol, 0·5; ethylic ether, 1·18–3·76; benzine, 4·70; pure water at 18° C., 25·0 (approx.). All *very dilute* (about 10^{-5} grm. molecules per litre) aqueous salt solutions approach 1·00 megohm per cm. cube at 18° C. *To reduce creeping* cover electrolyte with layer of heavy mineral oil, or thickly smear containing vessel above electrolyte level with vaseline. *Carefully exclude all dust.*

SPEED CONTROL OF D.C. MOTORS.—The speed of a d.c. motor depends upon the voltage applied to the armature and upon the strength of the field (the steady speed being that at which the back e.m.f. is less than the applied voltage by an amount which suffices to drive through the armature the current corresponding to the mechanical output of the motor at that moment). The speed may be varied by altering *either* the applied voltage *or* the field strength *or* both of these factors.

Speed and Power.—Whatever the method of speed control employed, it is important that the power requirements at maximum and minimum speed should be determined accurately and specified when ordering the motor and control gear.

Speed Control by Voltage Variation may be effected by: (1) series resistance; (2) series-parallel connection of two or more motors; (3) variable voltage supply on the 3- or 5-wire principle, or by using boosters to raise or lower the supply voltage as required.

1. The use of *series resistance* is a simple but inefficient means of varying the motor speed. A controller for speed control by this method is practically identical with a motor starter, except that the contacts and resistances are designed to carry current more or less continuously. Apart from the waste of energy involved by speed variation by series resistance, the voltage drop in the latter varies with the current, *i. e.* the speed of the motor varies with the load. Plain series control is only applicable to constant-torque loads, *i. e.* to motors requiring practically constant current. The power in such cases is practically proportional to the speed. Series resistance can, of course, only reduce the speed of the motor below normal.

A controller for *continuous service* is usually one in which the contacts and resistances for speeds up to half full-speed are designed and used only for starting purposes. The remaining contacts and resistances are designed to carry full-load current

continuously, and can therefore be used to provide continuously any speed between half-speed and full-speed. Controllers rated for *intermittent service* are generally either "2-minute" or "5-minute" controllers; in the first case the resistances may be in circuit for $\frac{1}{2}$ min. on the first contact and $1\frac{1}{2}$ mins. equally divided between the remaining contacts; in the 5-minute controller, the corresponding periods are 2 min. and 3 min. respectively. In either case the complete cycle (starting and cooling) is at least 15 min.

2. *Series-parallel control* is used in practically every d.c. traction equipment. Two similar motors are connected in series for speeds up to half-speed and in parallel for higher speeds up to full-speed. Series resistance is used to obtain other speeds, but the series and parallel connections respectively give half- and full-speed without rheostatic losses. A drum controller (or contactors controlled by a master switch of the drum-type) is used to effect the requisite changes in connections. Speed variation by field control may be used instead of, or in addition to, series resistance, and the field control itself may be by resistance or by series-parallel connection of the field windings.

3. *Variable voltage control.* (*a*) *Three-wire and Five-wire Supply.* A motor which can be connected between the outer and inner, or between the outers of a 3-wire system, is clearly in the same position as each motor of a series-parallel combination in point of having two "full-efficiency" speeds. Similarly, if a works has its own generating plant it is possible (by using generators with double-wound armatures or a larger number of ordinary generators) to distribute four different voltages by five cables. Motors can then be operated at any one of these voltages, or various combinations of these voltages, and there is thus obtained a wide range of speeds without rheostatic losses. This system has not gained much favour, the cost and complexity of the 5-line distribution and special generator equipment offsetting the advantages of the system in other respects.

(*b*) *Ward Leonard Variable Voltage Control.* This system is applicable to large motors from which wide speed variation is required in both directions of rotation. The motor is a separately excited shunt-wound machine, and the armature is connected directly to the armature of a shunt-wound generator (driven by constant speed motor or engine, as may be more convenient). The generator field, and hence the generator voltage, is variable between positive and negative maxima. The speed of the motor supplied from the generator varies with the voltage of the latter, and is therefore controlled simply by means of the generator field rheostat, which acts both as starter and speed regulator for the motor. No heavy current starting-gear is required, but the variable voltage generator and its driving motor must each be equal in rating to the motor supplied by the generator. The

outlay on auxiliary machinery may be reduced by using a generator and motor connected in series to act as a booster. The booster adds its voltage to, or subtracts it from, the line voltage, and thus furnishes the main motor with a pressure variable continuously from zero to twice the line voltage.

(*c*) The *auto-regulator system* recently installed on the Metropolitan Railway of Paris represents an important advance in d.c. traction motor control. A constant current reversible booster is used to eliminate resistance losses and makes possible regenerative braking. Control is effected by adding the booster e.m.f. to, or subtracting it from, the line pressure. In Fig. 24 M_1 M_2 represent standard series traction motors; F_2 a constant speed compound motor direct coupled to a machine F_1, which is excited by a shunt winding E and reversible winding H. The armature of F_1 is in series with the machines M_1 M_2 and reversing switch 3. On starting, F_1 drives F_2 and returns current to the line; as the main motor back-e.m.f. increases, that of F_1 decreases, and when it becomes zero, the motors operate in simple series across the mains. The e.m.f. of F_1 then reverses and increases; when it equals the line pressure, the main motors operate as though they were in parallel across the mains. The motor current is held constant and the line current varies over a 1 : 2 range. By reversing the switches 2 and 3, the regulator set is made to return current to the line, the main motor being meanwhile efficiently braked. To secure stable conditions and smooth working, the main motor field coils are shunted by the armature of a third auxiliary machine mounted on the booster shaft and excited by shunt windings across the regulator terminals and line respectively. The net increase in weight as compared with resistances and contactors, etc., is 3% to 5%; the corresponding saving in energy is about 20%. This system of control is easily adapted to one-phase working.

Speed Control by Field Variation.—In the case of d.c. shunt motors, efficient speed control over a wide range is obtainable by inserting more or less resistance in series with the field winding, the voltage applied to the armature remaining constant. The speed of practically any shunt motor can be increased 50 or 100% by this means, and if the machine be designed specially (notably as regards commutating characteristics) the speed may be raised to three or four times normal, or even higher, by weakening the shunt field strength. It would be possible to use an ordinary shunt motor starter (Fig. 20 or Fig. 22), a variable resistance being inserted in the field circuit. It is desirable, however, that the motor should always be started with full field, and this may be secured by using the starter shown in Fig. 24*a*. This is a slight modification of Fig. 22, the last contact C of the starter being extended and the sector S being cut below this contact to form

a separate stud T. The field rheostat R_f is connected between S and T. Until the last contact is reached full field is maintained via the sector S, but, on moving over C, the field rheostat is inserted and the speed of the motor can then be controlled. This arrangement is the more desirable the greater the range of speed provided by the field rheostat, because the risk in starting with minimum field is greater the lower the minimum field. A weak point in the design shown by Fig. 24*a* is that the motor speed is increased abruptly when the starter-handle reaches T, if the field rheostat be far from its low-speed position. This risk is overcome by the arrangement shown diagrammatically in Fig. 25, which ensures : (*a*) That the motor be started with full field; (*b*) that the field resistance be inserted gradually after the motor has been brought up to normal speed. It will be seen that the starter and speed regulator form a single piece of apparatus, the two arms A,B working on the same spindle P. To start the motor, A is moved to the right and carries with it B, full-field excitation being meanwhile provided through the contact strip C. When the starter is full "on," the field current must flow via arm A, by moving which back (B being held on by M) more or less resistance is inserted in the field circuit and wide speed control is obtained. On the occurrence of an overload, failure of supply or interruption of field circuit, B is released, and, flying back by spring control, carries with it the arm A. B cannot be moved forward alone, nor can A till B is held by M. This starter and regulator is suitable for machine tool and other motors having a wide speed range, and it is fool-proof in action.

Combined Resistance and Field Control.—This is made possible by the type of starter and regulator illustrated in Fig. 25*a*, which may be regarded as a modification of the apparatus illustrated in Fig. 25. A sector S provides for full field during the starting period, and the starting resistance R_a is proportioned so that it will carry continuously the current corresponding to each step, *i. e.* this resistance is used for speed regulation by the series-resistance method, as well as for starting. When the starting-handle reaches sector T the conditions are those of a plain starter in the full-on position. Further movement of the starting-handle inserts resistance R_f in the field circuit. So long as supply is maintained, the handle H will remain on any desired step, the pawl P engaging with the teeth *t*, but if the no-volt release operates, the pawl falls out of engagement with the teeth and the arm H is pulled "off" by its spring. Efficiency is sacrificed on the low-speed (series) steps, but for given total speed range the motor is smaller than with shunt control alone.

An elaboration of this method of control is illustrated by Fig. 26, and is useful where steady crawling speeds are required, in heavy printing presses, etc. A cumulative compound wound motor is

used to obtain high starting torque, and at (I) the machine is being started with resistance in series and full field. At (II) a "diverter" resistance is placed across the armature to limit the current through the latter and make possible steady running at crawling speed. At (III) the diverter resistance has been increased, permitting the speed to rise. At (IV) the diverter and the series resistance have both been cut out. At (V) a diverter has been placed across the series field and the latter has been short circuited. At (VI) maximum speed has been reached by inserting resistance in the shunt field. At (VII) supply to the armature has been interrupted and the latter has been short-circuited through the armature diverter; the shunt field remaining excited, a very powerful braking effect is produced.

A.C. MOTOR STARTERS.—*Single-phase commutator motors* are started by means of series resistance and starting switches

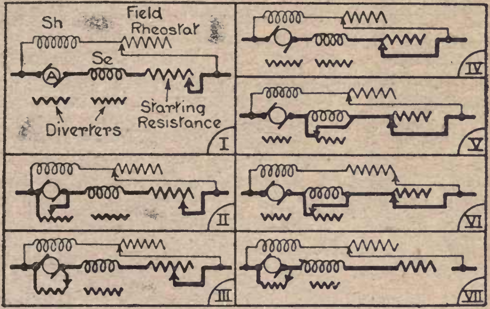


FIG. 26.

similar to those used for d.c. motors, except that modifications are required in hold-on coils, contactors, etc., for a.c. operation. Special types of compensated a.c. motors may be started very efficiently by brush-shifting or by aid of auto-transformers. Self-starting *single-phase induction motors* are available requiring no other switchgear than a d.p. main switch, such internal variations of conditions as occur during starting taking place automatically. In other cases the motor has a squirrel-cage rotor and either a 2 ph. stator winding (one phase being an auxiliary starting-winding) or a 3-ph. stator winding. A rotating field for starting is obtained by producing a phase difference between the currents in the stator windings. Referring to Fig. 27, a resistance R (or capacity K) is placed in one phase during starting; for a 3-ph. winding, terminal (1) is omitted and an inductance L is connected as dotted; when the motor is up to speed two phases in series are connected across the mains.

Two-phase induction motors may be started by connecting all the windings of each phase in series during starting; for running, the windings of each phase are in two equal circuits in parallel.

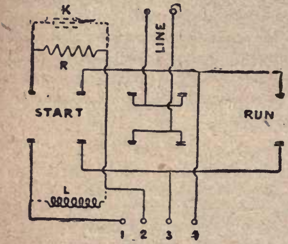


FIG. 27.

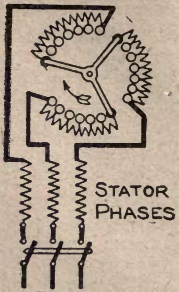


FIG. 28*a*.

This system of starting is equivalent to the use of a 50% auto-transformer.

Three-phase Induction Motors.—Small 3-ph. induction

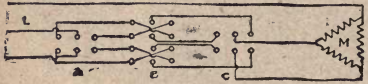


FIG. 27*a*.

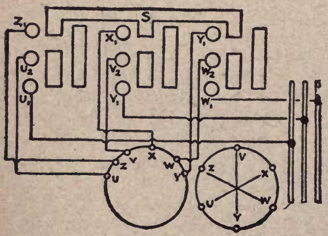


FIG. 28*b*.

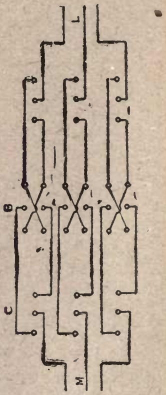


FIG. 28.

motors may be started by switching straight across the mains; the starting current is then about six times and the torque about twice full-load value. The maximum horsepower of machine which may be so started depends principally upon the starting

current permitted by the supply authority. Central stations in this country often insist upon a starter being used with every motor, but in the U.S.A. squirrel-cage motors of 50 h.p. or over are often switched directly onto the mains. This causes such a current rush and voltage dip that it can only be permitted on power mains, and in any case the electrical and mechanical shocks are very severe. Even when not demanded by supply regulations it is good practice to use reduced stator pressure or star-delta starting for machines over 5 h.p.

Figs. 27*a* and 28 show wiring connections for three-point control of 3-ph. motors which can be started direct on mains. All three sets of switches (which are mechanically coupled at each station) must be closed either to right or left at all times. No synchronising or current-reducing arrangements are made; phase connections of the motor are always the same. The motor can be started or stopped from A, B or C. In Fig. 27*a* a three-pole main switch and fuse-board should be provided to the left of A; in Fig. 28 the motor is completely disconnected from the line when idle, but more switches and wiring are required. High resistance in the rotor circuit (internal or external) secures high starting torque, but, for efficiency, the rotor resistance should be as low as possible during actual running.

Three-phase squirrel-cage induction motors may be started by *stator resistance* as in Fig. 28*a*; the series resistance limits the starting current, but the motor often will not start until the rheostat is well advanced, because the starting torque varies with the square of the voltage applied to the stator. If the rotor be phase-wound the motor is started with full resistance in each rotor phase and the stator fully excited.

A *star-delta switch* offers a convenient means of applying reduced voltage to the stator for starting. The stator phases are connected to six terminals, and a change-over knife-switch or a drum switch is used to connect the phases in star for starting and in delta for running. The pressure applied to each phase is $1\sqrt{/}3$ *i. e.* 58% of the line voltage during starting; this usually corresponds to a starting current about $1\frac{1}{2}$ times full-load current, and a starting torque about $\frac{1}{3}$ full-load torque. Fig. 28*b* shows a 3-ph. star-delta starting switch for squirrel-cage motors. The stator phases are in star till the rotor acquires about $\frac{3}{4}$-full speed, after which normal delta connection is restored. The motor develops about full-load starting torque while taking about twice full-load current. In the star setting, U_1, U_2; V_1, V_2; W_1, W_2; and X_1, Y_1, Z_1 are connected; in the delta position of the switch, the three vertical rows of contacts are connected. Continuous rotation of the starter drum provides star, delta and off connections. From normal running, " off " can be reached without returning through the star connection.

By using an auto-transformer a reduced voltage (or several

voltages in succession) can be applied to the stator for starting. The reduced voltage may be any desired fraction of the line voltage; the losses of the stator resistance method are avoided, and a heavy starting current may be used between auto-transformer and motor without taking excessive current from the mains. Up to 20 h.p., tappings giving 50, 65 and 80% of line voltage may be employed, corresponding to 25, 42 and 65% of "direct connection" starting current. Over 20 h.p., 40, 50, 70 and 84% line voltage, corresponding to 16, 34, 50 and 72% of "direct connection" starting current. Motor current varies directly with stator voltage; line current and torque vary with square of stator voltage.

Synchronous motors may be run up to speed (on light load) by auxiliary d.c. or induction motors, or they may be started as induction motors by applying reduced line voltage to the stator.

Newbury gives the following average *starting torques* and *starting currents* (as multiples of the full-load values):—

Motor, etc.	Torque.	Current.
One-phase induction, with clutch, split-phase starter	1–1¼	4½–6
" " no clutch " "	2	3½–4½
Polyphase " cage-wound, auto-transformer	2	7–8
" " phase-wound, resistance starter	1	1¼
" " " " " "	2	2½
Synchronous, auto-transformer starter . . .	0·3–0·5	1½–2½
" " " " . . .	0·7–1·0	4–8
Rotary converter " " . . .	0·2	1½

Overload and No-Volt Protection.—Any type of a.c. overload and no-voltage circuit breaker, with or without time-limit, may be applied to a.c. motor circuits. Owing to the heavy starting current of induction motors, the starting switch is often arranged so that heavier fuses are in circuit during starting than during normal running.

SPEED CONTROL OF A.C. MOTORS.—Insertion of series resistance in the rotor phases of a 3-ph. slip-ring motor gives speed control comparable with that obtained by series resistance in d.c. motor circuits. A more efficient method applicable to large motors is to use an auxiliary motor to utilise more or less "slip energy" from the rotor of the main machine. Two speeds are obtainable by arranging the stator windings so that the number of poles can be changed in the ratio 1 : 2. Three or four speeds are obtainable by pole-changing combinations in a double-winding stator. Two or more speeds may be obtained by various cascade connections of two motors, or even in a single motor. Synchronous motors are constant speed machines. Some of the special types of a.c. commutator motors are capable of speed regulation by autotransformer or by varying the brush position; for details see textbooks on a.c. motors.

ACCUMULATOR NOTES.

General.—The common lead accumulator, secondary or storage cell, consists of two or more "formed" lead plates immersed in dilute sulphuric acid (H_2SO_4) as electrolyte. The object of using a number of plates is to obtain a sufficient surface of active material to give the desired cell capacity, and since the latter depends so greatly on the positive (peroxide) plate area, it is usual to fit one more negative than positive plate. The plates are arranged alternately (Fig. 29), each group being lead-burnt on to leaden bars terminating in lugs forming the $+^{ve}$ and $-^{ve}$ terminals of the cell. Any required number of cells are connected in series or parallel as may be necessary. Lead is chosen as the material for the plates since the necessary electrolytic action takes place readily and may be indefinitely repeated without serious loss of efficiency; further, the electrodes $Pb.O_2$ (lead peroxide), and Pb. (spongy lead) yield, in dilute H_2SO_4, a reasonably high P.D. (2·0–2·2 volts).

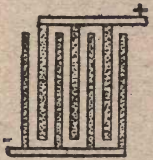


FIG. 29.

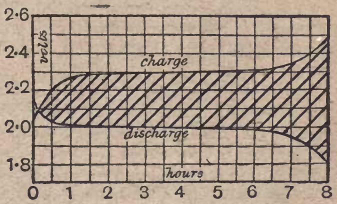


FIG. 30.

Chemical Action.—When accumulator plates are properly formed (*see* below) there is a layer of active material on each which may be regarded as $Pb.SO_4$ when the plates are completely discharged, *i. e.* when the cell is "run down" we have-

	$+^{ve}$ *Plate.*	*Electrolyte.*	$-^{ve}$ *Plate.*
	Lead sulphate.	Water.	Lead sulphate.
Discharged	$Pb.SO_4$	$2H_2O$	$Pb.SO_4$
or	$\boxed{Pb.}\cdot\boxed{SO_4 \quad H_2}$	$\boxed{O_2}$	$\boxed{H_2 \quad SO_4}\cdot$ Pb.

The action of a charging current (flowing from + to — through the cell), is to dissociate the lead sulphate and water molecules, enabling the reunion of their components, as shown by the bonds above, so that, when charging is complete, we have—

	$Pb.O_2$	$2H_2SO_4$	Pb.
Charged..	Lead peroxide.	Sulphuric acid.	Spongy lead.
	(chocolate : anode)		(white-grey : kathode)

The action is really more complex than would appear from these equations, but for the present purpose this simple view of the action is quite sufficient. The most important discrepancy between the conditions assumed above and actual practice is that the above equations assume the reduction of the electrolyte to pure water (sp. gr. 1000) at the completion of discharge. This is impermissible for obvious reasons, and it is usual, in practice, to employ such a bulk and strength of acid that its sp. gr. varies from 1170 (discharged) to 1220 (charged).

The action of discharge is the inverse of the above process, the electrolyte becoming less dense and the plates becoming gradually converted to $Pb.SO_4$. The couple $Pb.O_2$,Pb. yield, in dilute H_2SO_4 as electrolyte a voltage which rises to 2·4 or 2·6 volts near the completion of charging, falls rapidly to 2·2 volts on commencing discharge, and thence gradually decreases to 2·0 volts. The decline below 2·0 volts is comparatively rapid, and when 1·80–1·85 volts per cell is reached, discharge must cease cr permanent sulphating of the plates occurs. Fig. 30 shows typical charge and discharge curves for lead accumulators: the shaded area represents the lost volts which account for the difference between the ampère hour and energy efficiencies (*see* later).

During the discharge of a cell the materials on both plates expand greatly: thus 100 cc. spongy lead yield 290 cc. $Pb.SO_4$, and 100 cc. $Pb.O_2$ yield 186 cc. $Pb.SO_4$ (to the increased bulk of the $Pb.SO_4$ the whole porosity of the Planté plates was due). If now this expansion is not allowed for, the active material will disintegrate more or less, or the plates will buckle: grid plates have often proved too weak and too inelastic to withstand the strains due to the expansion. Should the active material of a plate scale or break away, the fragments may short circuit adjacent plates; apart from direct damage so caused, this leads to rapid and wasteful discharge of the cell, and prevents proper re-charge, *i. e.* the cell capacity is reduced. The unequal action caused, leads to plate-buckling, which, if not resulting in permanent short circuiting, will at least aggravate the conditions already obtaining. For these reasons plates should be carefully spaced by glass rods or wooden strips, and should be hung quite clear of the bottom of the containing vessel.

Current Density.—The maximum current during charge or discharge equals 4 to 8 amps. or, in exceptional cases, 12 amps. per sq. ft. of positive plate surface. Note that this important allowance is referred to the *positive* plate area, and that both sides of these plates are to be utilised and allowed for above. For effectiveness and efficiency the normal charging current should equal about two-thirds maximum charging current as

stated by the makers. The maximum discharge current should be 2 to $3\frac{1}{2}$ times the normal charging current.

Ampère-hour and Watt-hour Capacity.—The ampère-hour capacity and permissible final voltage of a battery vary with the discharge rate (*see* Table I). For ordinary services seven or eight hours' discharge at maximum current is a useful capacity. For special work a one-hour discharge and charge rate can be secured : such cells are costly and less satisfactory. The ampère-hour capacity of a battery of cells does not vary with the number of cells in series, but does vary with the number in parallel : the watt-hour capacity varies with the total number of cells, however arranged.

TABLE I. DISCHARGE DATA FOR LEAD ACCUMULATORS (Rankin)

Discharge Period Hours.	Rate of Discharge, in terms of 10-hr. Rate.	Amp. Hr. Capacity, in terms of Max. Capacity.	Min. Permissible Volts per Cell (Discharged).
10	1·00	1·00	1·83
8	1·19	0·95	1·83
6	1·46	0·88	1·83
4	1·95	0·78	1·80
2	3·17	0·63	1·78
1	5·0	0·50	1·75
$\frac{1}{4}$	9·0	0·22	1·70
Peak	12·5	—	1·60

Efficiency.—The efficiency of an accumulator may be specified on a quantity (ampère-hour) or energy (watt-hour) basis.

$$\text{The quantity or ampère-hour efficiency} = \frac{\text{Output in amp.-hrs.}}{\text{Input in amp.-hrs.}}$$

$$\text{The energy or watt hour efficiency} = \frac{\text{Watt-hours output.}}{\text{Watt-hours input.}}$$

The quantity efficiency Q may be 90%, and the energy efficiency E 80% : Q is always greater than E owing to the charging voltage always being greater than the corresponding discharging voltage.

Charging or discharging at high-current densities increases the heating and gassing losses and decreases Q and E. Rapidly alternating charge and discharge gives higher efficiency than more prolonged duration of each condition : " floating " batteries are the most efficient.

Thus the energy efficiency of a battery subjected to $\frac{1}{2}$ min. ch. and $\frac{1}{2}$ min. disch. = 90 to 97%; 5 min. ch. and 5 min. disch. = 87 to 93%; several hours ch. and several hours disch. = 70 to 80%.

Electrolyte.—Lead accumulators employ dilute sulphuric acid as an electrolyte. Acid made from iron pyrites by the contact process (using iron oxide as catalyser), frequently contains iron, which is a serious impurity in accumulator acid. It is possible to purify pyrites acid, but, comparing ordinary market grades, acid made from Sicilian brimstone by the lead chamber process is the best. Lead is not harmful except in excess. Iron in acid or topping-up water damages the $-^{ve}$ plates. Salt (in rain water near the coast, or from other source) combines with H_2SO_4 yielding chlorine which attacks the $+^{ve}$ plates. Ammonia and any metals electro-negative to lead must be carefully avoided: the latter would be deposited on the plates by chemical replacement and cause serious local action. The sp. gr. of the acid used should be 1·22 in the charged cells, falling to 1·18 at the end of discharge. The use of strong acid decreases the weight of electrolyte required, and also the number of cells required (by increasing the E.M.F. per cell—*see* Table), but increases the risk of sulphating the plates: 30% acid is the standard strength for ordinary purposes. Allowance should be made for about 0·001 loss of gravity per 30° F. temperature rise above 60° F.

Incidentally it may be noted that this strength gives maximum conductivity of electrolyte. It is the strength of the acid in the pores of the plates which really influences the behaviour and results of the latter: to ensure uniform electrolyte density a highly porous plate is needed.

Porosity.—The porosity of a plate is defined as the ratio $\frac{\Sigma \text{ volume of interstices}}{\text{Total volume of plate}}$: this should be as great as possible. A plate of ideal porosity would contain sufficient electrolyte in its

Strength of Acid.	E.M.F. per Cell.	Strength of Acid.	E.M.F. per Cell.
Per Cent.	Volts	Per Cent.	Volts.
Very weak.	1·60	50	2·17
10	1·93	60	2·24
20	1·99	70	2·31
30	**2·05**	80	2·38
40	2·10	90	2·48

pores to be independent of diffusion with the main body of the electrolyte. This necessitates a porosity of 94% or, allowing for the fact that lead accumulator plates are only half sulphated when "discharged," a porosity of 92% and 89% for the $-^{ve}$ and $+^{e}$ plates respectively. Early Planté accumulators had

a porosity of 25% only, but "Chloride" cells now reach 60% to 70% porosity (= 70% to 80% ideal value). High porosity enables rapid charging and discharging without danger, and does not necessarily entail extreme mechanical weakness.

Allowance of Electrolyte.—A considerable excess must be allowed beyond the value given by the chemical equations expressing the action. For *Central Station* work, allow 10 to 20 lb. electrolyte per 100 amp.-hrs. of cell capacity. For *Automobile* and similar work allow 5 to 8 lb. electrolyte (stronger than in previous case), per 100 amp.-hrs.' capacity.

Total Weight of Lead Accumulators.—On the above basis the total weights are: *Station Work.*—0·33 to 0·50 × [capacity (amp.-hrs.)] lb. *Traction or Submarine Work.*—0·17 to 0·25 × [capacity (amp.-hrs.)] lb.

Commercial Types of Plates.—(*a*) **Planté Derivatives.**—*Tudor* $+^{ve}$ plates are cast in one piece with a large number of deep, thin vertical ribs and a fewer number of horizontal strengthening ribs (ten times the surface of a smooth plate of the same overall dimensions is thus secured). The $+^{ve}$ plates are formed by the Planté process; the $-^{ve}$ plates, of the same pattern, are pasted.

"*D.P.*" *Cells* have a positive "formed" for use by electrolytic action, giving a tough and adherent coating of lead oxide. The positive plate is a cast one of the hanging type, constructed of numerous vertical ribs, intersected at regular intervals by horizontal binding ribs, resulting in a rigid structure which is capable of expanding in any direction without buckling, and allowing of a free circulation of the electrolyte right through the plate. The very large superficial area obtained in this way renders it possible to obtain an ample storage capacity with a very thin skin of peroxide, so that undue weakening of the metallic support by the formation of a very heavy skin upon it is avoided. The perforated screen which covers the face of the plate prevents the active material from falling out, and at the same time allows free circulation and access to the active material of the electrolyte. The sectional area of the support is ample, and this not only reduces the internal resistance of the cell, but is a guarantee of its lasting properties.

Epstein Process.—Corrugated lead plates (Fig. 31) are heated to boiling in 1% nitric acid till dull grey in colour; they are dried in air and then "formed" in dilute sulphuric acid, to which a small percentage of pyrotartaric acid is added, till the grey-yellow colour changes to deep brown or bluey-black: the plates are then ready for use.

(*b*) **Faure Derivatives.**—*E.P.S.* plates are of the pasted

type; the $+^{ve}$ and $-^{ve}$ grids are as shown in Fig. 32 (high rate of discharge type): the fresh paste is partially formed or "hardened" by electrolysis in dilute H_2SO_4. The complete "formation" is effected by the purchaser in the specially long, slow charge always given to new accumulators when first placed in service.

Hart plates are similar in many respects to the E.P.S. type, but have a characteristic form of "girder lattice-work" grid with diagonal ribs and special pellet clamping lips. Minium (red lead, $Pb._3O_4$) is used on the $+^{ve}$ plates and litharge (Pb.O) on the $-^{ve}$ plates.

Chloride Cells.—For the plates used in this cell a grid of antimonial lead is cast, and into a series of $\frac{3}{4}$ in. holes provided spiral rosettes of gimped, pure lead tape are driven and riveted by

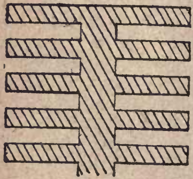
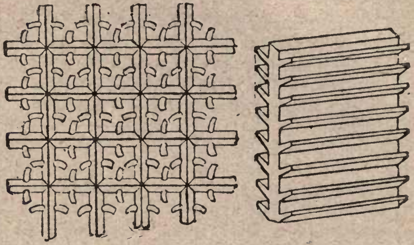


FIG. 31.



Negative Grid. Positive Grid.

FIG. 32.

hydraulic pressure (the plate holes being doubly tapered somewhat as in the E.P.S. grid). Of these plates the positives are formed by the Planté process. The active material of the negatives is contained in "boxes" formed by riveting together two half-plates, after inserting the active material, escape of which is prevented by perforated cover-sheets of lead.

Installation Points.—Make sure the battery is large enough for its work; ask for a 100% capacity-maintenance guarantee. Charging plant should be able to give full charge; milking booster should be able to charge low cells at *normal* charging current. *Number of Cells Required.*—To provide a terminal p.d. $= V$ volts, use $N = (V/e)$ lead cells where e has the following values :—For 5-10 hr. disch., 1·83; 2-4 hr. disch., 1·78–1·8; 1 hr. disch., 1·75; buffer batteries 2·05. To cover the decrease in the e.m.f. per cell (from 2·4 or 2·2 to 1·85 v.) as discharge proceeds, a booster may be used in series with the battery, or, n end cells may be installed; using double cell switches, $n = N—V/2{\cdot}7$; using

simple battery switches, $n = N—V/2{\cdot}1$. Up to 200 v., the regulating switch controls single cells; at 220 v. two, and at 400 v. or over, three or four cells are connected between each pair of regulator contacts.

Accumulator Rooms should be light, dry and cool, and large enough to accommodate all cells on the floor; small cells *may* be in two tiers, but this tends to costly and inefficient maintenance. Exclude sunlight, dust and fumes (particularly chlorine, ammonia, vinegar and nitric acid). Accumulator acid freezes at 4° F., but it is advisable to warm cold rooms. Ironwork must be and woodwork should be covered with acid-proof paint; tar or pitch not recommended; glazed walls advisable. Window ventilation best; ventilating fans soon destroyed by acid fumes. *Flooring.*—Metalline bricks laid on edge and bedded in grouting on cement screed of concrete floor. Cells on glazed insulators and weight of battery taken through to main body of floor by the impermeable bricks. Cement finish to floor covered with acid-proof asphalte, which is also run between bricks above the grouting. Pure Trinidad asphalt with 3·5 parts by weight of quartz sand is an acid-proof mixture. Woodwork—pitch-pine; dry and painted with linseed oil or Heising varnish. Use no iron nails or screws in building stands; mount cells on lead discs on insulators. "Burn" connections where possible; paint connecting bolts. Leave no metal tools in the room.

Care of Cells.—Keep cells in regular service and as fully charged as possible. Avoid excessive charge or discharge current; min. permissible voltage on discharge depends on rate of discharge (Table I). Check all measuring instruments at intervals. Never depend absolutely on any instrument. Tighten bolted lug connections frequently for lead is weak in compression. Keep plates covered because each sq. in. of bare plate means proportionate loss of capacity. Also, exposure to air is injurious, the negatives becoming thoroughly discharged and the positives suffering corrosion. Free acid circulation is required round the positives to prevent corrosion. "Topping up" water should be introduced through a tube reaching to bottom of cells; then, as it rises, it mixes the electrolyte; otherwise there is a top layer of dilute acid which encourages corrosion. *Consult makers when in trouble; always observe their instructions.*

Charging.—The first charge is *very important.* Fill the whole battery as quickly as possible; start charging at once, without interruption for at least 24 hr. and preferably for the whole 40 to 60 hr. occupied by the first charge. The charging current should be $\frac{2}{3}$ normal unless the temperature rises above 100° F. Constant sp. gr. of acid *together with* constant cell voltage are

reliable signs of full charge; a sulphated cell will gas freely before fully charged, and if charge be continued, gassing and cell volts both *decrease* again until the sulphate is destroyed and the cell truly charged. Charging at excessive current causes injurious heating and wasteful gassing, which also breaks up the active material on the positives. Charging at too low current encourages sulphating of the positives, and is liable to occur when charging small cells from charging-boards and large cells from milking boosters. *Overcharge.*—The rule to give 10% more charge than the discharge output (under the control of special amp.-hr. meters or otherwise) is *arbitrary and unreliable.* The *minimum* overcharge required is [100 (100-p)/p]%, where p = amp.-hr. efficiency of the battery; *i. e.* 11% overcharge for cells of 90% efficiency and 25% for 80% efficiency; more overcharge is needed if the charging current be higher than normal. The only safe rule is to charge until *both* voltage and sp. gr. are constant; see that they remain so during a gassing overcharge once a week; if not, the plates are sulphated. In cells which charge slowly, look for short circuit between plates or in end cell leads or switches. Pay special attention to end cells Nos. 6–10 in 60 cell, 110 v. battery. *Logging Charge, etc.*—Instead of a laborious record of volts and sp. gr. for every cell, R. Rankin advises division of the battery into a few sections in each of which a "pilot cell" is chosen. Acid level must be maintained in the latter and no short circuit permitted. Volts and sp. gr. must be logged for pilot cells at end of charge and discharge and current noted when readings are taken. Give gassing overcharge once a week for ½ hr. at ½ normal current. During each charge, note any cell lagging behind its pilot in commencement and amount of gassing; probably it needs attention and extra individual charge. Important points are to keep the pilots in good order; to base charging of the other cells on the behaviour of the pilots; and to record details of all troubles and cures.

Dismantling Cells.—During long idle periods open all switch contacts. Never leave plates discharged (in acid) for long; charge idle batteries at least every 2 months. If the battery cannot be kept charged (which is best) it may be dismantled by charging every cell completely and then discharging at 5 hr. rate to about 1·5 v. per cell, so as to form a protective skin of sulphate on the negatives. Then empty cells and cover over. A "first charge" is needed when the cells are returned to service.

Sulphating may be caused by standing idle, by too strong acid or by over- or too rapid-discharge. Moderate sulphating may be removed by long continued charging at moderate current; do not discharge rapidly until cured. The insulating skin of white lead sulphate on badly sulphated plates causes high resistance and low capacity. If long overcharge is ineffective,

try Penley's method of recuperation, viz. :—Charge damaged plates for 60 hr. at normal rate in a solution of 2 lb. *pure* sodium sulphate per gallon of water. Replace this solution by acid of correct strength, and the cell is ready for service after preliminary charge and discharge.

Acid Stains and Burns.—Apply strong ammonia solution to clothing and dilute ammonia, washing soda, whitening or lime-water to flesh (later covering with lint soaked in linseed oil). Keep ammonia, etc., away from cells.

Alkali Accumulators.— The active materials are iron and nickel, the electrolyte is 20% solution of potassium hydrate (sp. gr. 1·19), and under no circumstances attacks chemically any part of the cell. *Advantages.*—Great mechanical and electrical robustness; negligible maintenance, life claimed 10 times that of lead cells; ability to withstand long idle periods, heavy charge or discharge without loss or injury. No "sulphating" or analogous trouble. No offensive or corrosive fumes. Cells are light and compact. Ampère-hour capacity increases about 10% during early days of life and is generally at least 90% of rated value after 1000 discharges. Practically full ampère-hour capacity can be realised on 1 hour discharge; forced charging or "boosting" may be at 5 times normal rate for 10 min. or twice for 1 hour. *Disadvantages.*—Average working p.d. per cell is 1·2 volts, hence 70% more cells are needed for given voltage; to some extent this sacrifices economy of space which would otherwise be obtainable. For very low voltage car lighting, 1·2 v. is not a convenient submultiple of lamp voltages; this can easily be overcome by lamp makers.

Care and Precautions.—*Never* use acid in filling alkali cells; use distilled water and (once or twice a year) alkali solution. Keep cases clean, dry and insulated from each other; ventilate cells well during and for some time after charging; bring no naked flame near vents; keep face away from latter. Overcharge preferable to undercharge. Heavy current discharge should not be commenced with electrolyte cooler than 55° F.; a short heavy charge warms it if necessary. Temperature should not exceed 120° F. or 140° F. as absolute limit.

The Alklum Cell (British make) uses retainers for both plates made of thin perforated nickel strips mechanically locked at seams after filling, to form flat tube 10–15 mm. × 3–5 mm. A number of such tubes are securely joined to form a band which is fastened in a contact frame. The latter and the Ni containers are unaffected by charge and discharge. Active material is chiefly nickel oxyhydrate with graphite in positive; and finely powdered iron-cadmium alloy in negative plates. Lugs of plates of similar polarity welded together and to terminal bolt

which carries the plates. Hard rubber or porcelain spacers and supports in portable and stationary cells respectively. Containing case of welded steel, assembled through bottom, before bottom plate welded on; sides and bottom coated with insulating varnish. Available in capacities from 10 to 425 ampère-hours suitable for hand lamps, motor-car self-starters, car lighting and traction or stationary service. *Data.*—Charging volts rise slowly from 1·4 to 1·5 v. during first hours of normal charge, then suddenly to 1·8 v., at which it remains constant even during overcharge. Discharge voltage falls slowly from 1·3 to 1·1 v. and is near 1·2 v. most of time. Charge or discharge at 4 or more times normal permissible for short periods; electrolyte should not exceed 60° C. or 140° F. On normal charge and discharge: 13–16 watt-hrs. per lb.; 1·5 to 1·9 kw.-hrs. per cub. ft. (including terminal space): efficiency—60 to 65% on watt-hrs., 80 to 85% on amp.-hrs. (up to 75% and 95% respectively at ⅔rds capacity). *Cf.* 4 to 6 watt-hrs. per lb. and 8–12 watt-hrs. per lb. in stationary and traction lead batteries.

Edison Cell.—Positive plate uses nickel hydroxide and flake nickel in alternate layers pressed into perforated tube, made by winding strip nickel helically and securing it by small steel rings; opposite direction of alternate tube-helices prevents buckling. A 4 in. × ¼ in. tube contains over 600 layers; the tubes are held firmly in a nickelled steel frame. Negative plate uses iron oxide (with mercury for conductivity) enclosed in perforated steel, corrugated pockets pressed into steel frame. Rubber separators. Plates bolted together and to terminal post which passes through insulated, paper-packed stuffing glands in the welded top. Container of welded corrugated steel plates, nickelled and painted with insulating preparation. Hinged filler cap with gravity-valve provided. A-type plates 4¾ in. × 9¼ in.: B-type, 4¾ in. × 4⅝ in.; number after type letter denotes number of positive plates. *Action.*—During first charge green nickel hydroxide oxidised to black NiO_2 and iron oxide reduced to iron. During discharge iron re-oxidised and NiO_2 reduced to Ni_2O_3. *Data.*—Internal resistance in thousandths of 1 ohm = 450 ÷ Capacity in amp.-hrs. (approx.). Charging volts rise from 1·55 to 1·84 v.; average discharge 1·2 v. or 1·3 v. on low rate discharge. In emergency, 30% extra output by overcharging; temperature should not exceed 115° F. Normal discharge 8 to 10 amp. per sq. ft. active + or − surface. 7½ to 12 amp.-hrs. per lb.: 11 watt-hrs. per lb. in small, up to 15–17 watt-hrs. per lb. in large sizes. Ampère-hour efficiency 75–80%; watt-hour efficiency 55–60% (95% and 68% respectively under boosting conditions). Full capacity guaranteed for 6 years (stationary) or 4 years (traction). Available from 4 amp.-hrs. (miners'

lamps, etc.) to 500 amp.-hrs. in standard sizes; up to 12,000 amp.-hrs. for submarine and other special service.

Accumulator Applications.—Great numbers of accumulators are used for portable or semi-portable lighting sets; wherever a small quantity of electrical energy is required without a special generator; in telegraphy and telephony; and as reserve, light-load and peak-load equipment in central stations and private electrical installations. Vast numbers are used in electric starting equipment for automobiles (over 1 million in the U.S.A. alone in 1916). The electric vehicle has come to stay and will make increasing demands for medium power batteries of light weight and great strength. Very large batteries will continue to be used as central station auxiliaries.

Typical Large Battery.—Provision is made in the Met. El. Supply Co.'s Holborn substation for four batteries to increase the effective plant capacity. The first battery is of 110 chloride cells, type CVW. 26. The discharge amps. (A), and amp.-hrs. (Ah) for stated periods and to stated min. volts (V) per cell are :—1200 A, 10 hr., 1·8 V, 20,000 Ah; 2000 A, 5 hr., 1·78 V, 10,000 Ah; 3800 A, 2 hr., 1·7 V, 7600 Ah; 6000 A, 1 hr., 1·65 V, 6000 Ah; 8000 A, 35 min., 4667 Ah; 12,000 A, 1 min., 200 Ah; 15,000 A momentarily. The charging current is 1400 A normal, 2570 A max. *Guaranteed Efficiency.*—90% amp.-hr. at all rates; 75% watt-hr., 5 hr. rate; 72%, 2 hr.; 70%, 1 hr. Construction of plates already described; *positives* 26 per cell, $16\frac{1}{8} \times 46\frac{3}{8} \times \frac{7}{16}$ in., 90 lb. each; *negatives* 27 per cell, $16\frac{1}{16} \times 46\frac{3}{8} \times \frac{5}{16}$ in., 41 lb. each; special wooden diaphragms. Complete cell $21\frac{3}{4} \times 49\frac{1}{8} \times 65\frac{7}{8}$ in. overall; weight complete 6080 lb., including 3452 lb. plates and 1700 lb. acid. Total weight of battery without stands, 300 tons. Special ventilation trunks with l.p. fan supplying fresh air and h.p. fan extracting foul air.

Lead and Nickel Cells for Submarine Service.—Reliability all important: weight requirements not so stringent as in traction work. The information to the left and right of the vertical strokes refers to lead and Edison cells respectively. Elements—Pb. in H_2SO_4/Fe-Ni in potash. Forcing, up to 1 hr. disch.—(permissible/not permissible). Weight/h.p. hr. capacy. ($3\frac{1}{2}$ hr. rating)—78/72 lb. Space occpd. per h.p. hr.—0·41/0·51 cub. ft. First cost per h.p. hr.—78*s.* 6*d.*/280*s.* Mean disch. v. per cell—1·92/1·2 volts. Pressure drop on disch.—10%, 18%. Efficiency—90%, 75% amp.-hr.; 75%, 55% watt-hr. Life—400 disch. (experience) /800 disch. (guaranteed). Clean once in two years in both cases. Limited space, rather than weight restrictions, has been determining factor in past. Batteries for American submarines in 1916 said to be 2 sets of 60 cells; weight 60–70 tons complete; each section 12 × 12 × 4 ft.; total capacity 3000 amp.-hrs.

TRANSMISSION CONDUCTORS AND CABLES.

Conductor Material.—Factors which must be taken into consideration include specific resistance, specific gravity and breaking strength of the material (for aerial wires), prime cost, durability and cost of maintenance. For aerial conductors, Snell has introduced a *figure of merit* F = (*tensile strength*)/(R × S × P), where S = specific gravity, P = price per lb., R = specific resistance, which is such that the larger its value for any given metal, the more desirable is the latter as a conductor material. On this basis, the relative cost of other than copper aerial conductors of equal length and resistance = (S × P × R)/($s \times p \times r$), where S, P, R and s, p, r refer to the first and second conductor metals respectively.

Hitherto, copper has been generally employed as a conductor material, but, during recent years, its price has been so high that much attention has been paid to the *use of aluminium* as a substitute. An aluminium conductor must be about 1·65 times as great in cross section as the copper conductor of equal conductivity, and a useful rough rule is that aluminium is the more economical material for bare conductors whenever its cost per ton is less than twice that of copper. The chief practical objection to the use of aluminium in this connection is the difficulty of jointing it. Aluminium cannot be soldered, but satisfactory clamped or cast joints can be effected. As regards supporting its own weight, aluminium is practically equivalent to steel. There are now in service a number of high and low pressure insulated aluminium conductors. The larger aluminium section required for given conductivity involves additional outlay on insulating material, but there are in use a number of low tension aluminium exceeding 1000 sq. mm. conductor area, and the Copenhagen Tramways Authorities find that about 15% economy may often be realised by using aluminium in preference to copper for direct current cables of large section. Steel conductors are sometimes used for very long aerial spans (across rivers, etc.), and in the shape of cable armouring or old steel ropes for earth return purposes, but the high specific resistance of the metal and (where alternating current is concerned) its magnetic qualities are serious disadvantages. A mild steel conductor has 9·1 times the sectional area, 8·1 times the weight, and 26·7 times the tensile strength of a soft copper conductor of equal conductivity.

Zinc and Iron Conductors.—Owing to war shortage of copper in Germany, zinc and iron have been used for wiring, cables and motors, transformers, etc., up to 100 kw. or possibly 250 kw. With the exception of Fe wiring for some domestic

purposes (*see* Wiring Systems and Methods) there is no likelihood of these substitutes being used permanently. Zinc cables must be stranded to reduce risk consequent on local flaws; minimum total section at least 16 sq. mm., say 7/15 S.W.G. or equivalent. Bare Zn lines would corrode rapidly. Zn cables must be handled gently during erection; not bent to less radius than 25 diameters; and not moved in cold weather. Mechanical clamps safer than soldering. High temperature, due to solder, molten insulating compo or other cause, induces change in crystalline structure and brittleness. It is claimed that lead-sheathed zinc and paper cables are satisfactory and that rubber-zinc cables can be drawn into conduit. Current density may be half as great in Zn as in Cu conductors for equal temperature rise; latter should not exceed 45° F. for Zn. At 68° F. (20° F.) resistances in ohms per mil-foot and relative conductivities are:—Cu 10·7 ohms (100); Al 18·4 (58·4); Zn 37·6 (28·5); 86 (12·5).

Conductor Cross Section.—The carrying capacity of a conductor depends largely upon the heating effect of the current conveyed. A very safe rule (Kennelly's) to follow is:—C (amps.) $= 560\sqrt{d^3}$, where $d =$ core diam. ins. The I.E.E. rules are based upon the formulæ:—C (amps.) $= 2 \times A^{0.775}$ (or log. C $= 0·775$ log. A $+ 0·301$), for conductors in situations exposed to temperatures exceeding 100° F.; and C (amps.) $= 2·6\ A^{0.82}$ (or log. C $= 0·82$ log. A $+ 0·415$) for other conductors. In these formulæ, A $=$ conductor area in 1000ths of a sq. in. The maximum temperature rise will be about 20° F. on large sizes. Though the sectional area of conductors should be proportioned to the heating effect of the maximum current to be carried, I.E.E. rules forbid the use of wiring conductors smaller than No. 18 S.W.G. wire, and recommend the stranding of all conductors of sectional area exceeding 0·005 sq. in. (No. 14 S.W.G.).

The table on page 138 shows the carrying capacity in amps. of various sizes of copper cables. To transmit say 35 kw. at 240 v. single phase and at a power factor other than unity (say 0·8), a cable is required which will safely transmit an "equivalent" power of (35/0·8) = 43·7 kw. at 240 v. = 182 amp., *i. e.* a 19/14 paper or fibre cable or a 37/·083″ rubber cable. Where three-phase current is concerned, the power must be multiplied by 0·578 and divided by the power factor; *e. g.* 80 h.p. at 0·75 p.f. three-phase 500 v. requires a cable capable of transmitting (80 × 0·578/0·75) = 61·6 h.p. at 500 v. = 92 amp., *i. e.* a 19/18 paper or fibre cable or a 19/·072″ rubber cable.

Pressure Drop.—In many cases the permissible pressure drop, as well as the capacity, has to be taken into account in determining the necessary size of conductor. Knowing the permissible

drop e volts and the current C amps. to be carried, the permissible resistance $R = (e/C)$ ohms, and the size of the conductor, of the desired length, having this resistance, is readily determined. *Sayer's wiring equation* is a simple extension of Ohm's law and reads :—$K = (Cl/e)$; where K = feet of cable per ohm resistance = a constant for each gauge of wire, which readily identifies the latter; C = average amps. carried; l = ft. of conductors (lead and return), e = volt drop in l ft. of conductor. The pressure drop in l ft. of cable (lead and return) worked at f amps. per sq. in. $= 0{\cdot}000008\,fl$ volts. Reference to the I.E.E. wiring table (p. 138) shows that from the point of view of current-carrying capacity, a 50 h.p., 500 v. d.c. motor (= 82 amp. input if efficiency = 91%) requires a 19/16 rubber cable. The same table shows the resistance of this cable to be 0·41 ohm per 1000 yd.; hence if motor be 350 yd. from switchboard, the pressure drop $= CR = 82 \times 2 \times 350 \times 0{\cdot}41/1000 = 23{\cdot}5$ v., which is excessive. A larger cable must be used than required by consideration of current density. If the max. permissible drop be e volts the resistance r (ohms per 1000 yd.) of the cable to be used is given by $r = 1000\ e/Cl$; where C = ampères carried, and l = lead and return in *yards*. In the above case, for $e = 5$ v., $r = 1000 \times 5/82 \times 700 = 0{\cdot}087$ ohm per 1000 yd., *i. e.* a 37/·104″ cable should be used. The question of voltage drop in supply conductors is of special importance in lighting circuits, for 1% variation in voltage (from normal) produces 3·7% and 5·6% candle-power variation in metal and carbon filament lamps respectively. The size of conductors and the arrangement of circuits should be such that the difference in voltage at the lamp terminal is constant within say 2%, however many lamps be alight. By suitably disposing the feeding points, much can be done to equalise the pressure drop in a network of lamps or other apparatus.

The three-wire system, if properly balanced, saves copper and reduces the distribution losses. The cross section of feeders may be reduced beyond tapping-off points according to the amount of current diverted at the latter.

Kelvin's Law.—*The most economical size of conductors is that for which the annual cost of interest and depreciation is equal to the cost of the energy dissipated in the conductor.* This law is based upon the principle that the capital outlay upon conductors varies directly with the weight of metal employed. More accurately, the law has been expressed by Forbes as follows :—*The most economical conductor area is that for which the annual value of the energy loss in the copper = (annual charges on total cost of line, including erection, etc.) — (that part of capital outlay which is independent of the conductor area).* If p = annual cost

of 1 e.h.p. at generator; R = line resistance; C = average current; A = conductor area sq. ins.; P_1 = total cost of line; P_2 = capital independent of A; P_3 = capital proportional to A; K = rate per cent. of annual interest; T = hrs. in a year; and w = constant, depending on energy wasted in conductors: Then $(pC^2R/746) = K(P_1 - P_2) = KP_3$ expresses algebraically Forbes' condition for maximum economy and—

$A = C\sqrt{(wpT/P_3K)}$ gives the best conductor area.

Insulating Cables.—A cable generally consists of a number of stranded copper conductors enclosed in an insulated sheathing. The current-carrying capacity of the conductor is determined as in the case of bare lines, reduced radiating coefficients being adopted to allow for the lagging effect of the insulating material. The *insulating material* or *dielectric* should possess: High specific resistance; mechanical strength and toughness, flexibility; and retentivity of insulating value under changes of temperature and contact with acids and gases. The specific resistance in megohms per cm. cube at 15° C. of certain commonly used dielectric materials are:—Siemens' high-insulating india-rubber, 16,170; pure rubber, 5000–10,000; Siemens' high-insulating fibrous material, 11,900; best vulcanised rubber, 4000; Siemens' ordinary vulcanised rubber, 2280; Glover's vulcanised rubber, 1630; paper (resin oiled), 3000; bitumen, 400; gutta-percha, 250–450. Dielectric materials may be broadly classified according as they are *non-hygroscopic* or *hygroscopic*. Materials of the former class are unaffected by moisture, and include rubber and various elastic or plastic rubber substitutes; those in the latter class include fibrous materials impregnated with insulating oils or waxes.

Rubber was the first dielectric to be used on heavy current cables. Its advantages include high insulation, easy erection and manipulation; and its use is likely to continue extending. A complete rubber cable comprises tinned conductors, a layer of pure rubber, a sheathing of vulcanised rubber and an outer covering of tape, braid or armour, etc. The conductors are tinned to protect the copper from attack by sulphur, and the rubber from the influence of the copper which is to encourage oxidation. Pure rubber oxidises readily and has an affinity for moisture, hence it is protected by the cheaper and more permanent material *vulcanised rubber*, which may be made by mixing 5% sulphur with pure rubber and cooking the mixture at 150° C. Many power cables have proved satisfactory with only 30% pure in the vulcanised rubber; about 60% pure may be considered high, 40% medium, 20% low and 10% entirely unsatisfactory. Vulcanised rubber is mechanically strong, flexible and capable of resisting fairly high temperature

Impregnated tape, applied over vulcanised rubber, protects the latter against atmospheric influences and prevents distortion of the dielectric during vulcanisation. Impregnated braiding affords valuable mechanical protection to cables which, for one reason or another, is not desirable to armour, *or* braiding may be applied over the armour to protect the latter. Tanned jute yarn is a more durable braiding material than cotton for use in damp situations. Coir yarn (made of cocoanut fibre) is practically incompressible, and is cheaper and less absorbent than jute. Simple gutta-percha coverings are only suitable for cables immersed in water between the temperature of 40° and 80° F., and, if necessary, provision must be made to prevent attack by marine insects.

Bitumen Cables.—The early cables of this class comprised copper conductors coated with a layer of pure bitumen, but it was found that the plasticity of the latter permitted the cores to become decentred. Vulcanised bitumen—made by sulphurising a product of distillation of bituminous oils—overcomes this disadvantage to a considerable extent, and forms the basis of several well-known insulating compounds. The mixture generally used contains cotton-seed pitch, Trinidad bitumen, and sulphur; pure bitumen forms only a small proportion of the whole. The admixture of cotton-seed pitch and sulphur overcomes to a great extent the cracking and flowing tendencies of pure bitumen; the elastic pitch softens at 120° F., hence bitumen cables must not be used in hot situations, and their inferior mechanical strength necessitates care in handling. Generally speaking, it is wise to confine bitumen insulation to single conductor cables, but Glover's "Cracore" bitumen cables—in which two or three individual insulated conductors rest on a central core or cradle of bitumen compound, the whole being overlaid with bitumen to form a cable—are now much used in mining and similar work. Bituminous composition injected in stranded conductors themselves, prevents water from penetrating to any appreciable distance through a fault.

Fibrous Dielectrics.—These consist of paper or jute or cotton yarn, impregnated with resin oil; or of varnished cambric. *Paper* is the usual dielectric in modern power cables and is applied in overlapping strips from 3 to 15 mils in thickness. It is usual to specify pure manilla paper, but many users claim satisfactory results for paper containing 30% or so of wood pulp. Paper cables are relatively cheap and very durable; they are less affected than rubber or bitumen by temperature, and there is very little risk of trouble from defects in material. Removal of moisture before impregnation, and permanent exclusion whilst in service are absolutely essential. The insulation resistance and puncture strength of dry, impregnated fibrous dielectrics are

high; and the low specific capacity is valuable in e.h.t. work. The principal disadvantage is that lead or bitumen sheathing is required to exclude moisture; also joints and ends must be sealed very carefully, hence paper cable is at a disadvantage where short lengths are concerned. *Varnished cambric, Empire cloth or lino tape* consists of very fine cambric coated with oxidised oil. The tape is applied spirally and an oily compound is used as lubrication between layers. This dielectric is practically non-hygroscopic and is unaffected by sulphuric acid spray or oil; it is useful in accumulator- and engine-rooms and for generator and transformer connections. If used for general power mains, lead sheathing must be provided.

Thickness of Insulation.—The thickness of the dielectric round any conductor is a function of the working pressure; specific resistance of the material used; size and shape of conductor. The smaller the diameter of a circular conductor or the sharper the corners of sector cores where these are used, the greater the thickness of insulation required for a given high pressure, owing to the higher intensity of electrostatic stress and the greater risk of brush discharge. The minimum radial thickness of various insulating materials required on various cables is specified in the table, pp. 162, 163.

Arrangement of Conductors.—Rarely more than two or three insulating cores are stranded together to form one cable under a common outer covering. The cores may be circular (not necessarily of equal diameter), sector shaped, or one central solid or stranded circular core may be surrounded by one or two concentric ring-formed stranded cores (with the intervention, of course, of the necessary thickness of insulating material). The great objection to the concentric type is the mechanical inaccessibility of the inner cores and the consequent difficulty of connecting tapping cables. For pressures up to 700 or 1000 v., sector cores reduce materially the cost and weight of cables, and the advantage in favour of their use is greater, the greater the percentage value of the copper section. Owing to the high dielectric stress at the corners of the cores, a sector cable requires greater insulation thickness than a circular core cable for a given high pressure, and this fact is of special importance, since a 40,000 v. cable, for instance, needs roughly four times as thick insulation as a 20,000 v. cable. The smaller the percentage of copper area, the less favourable become sector cores; circular cores should be used for high-tension cables if the copper area per core is less than 35 sq. mm. Sometimes circular (oval) cores are employed; in low-voltage cables these are less advantageous than sector cores, but for high working pressures they offer the advantage of having less acute corners than sectors.

MAXIMUM CURRENTS, ETC., FOR INSULATED COPPER CONDUCTORS
(I.E.E. RULES).

Number of Wires and Diameter of each Wire.	*Section.* Nominal Cross-sectional Area of Conductors	Rubber Insulated Cables. *Current.* Maximum Current Permissible.	Rubber Insulated Cables. *Volts Drop.* Approximate Total Length in Circuit (Lead and Return) for 1-volt Drop (Col. 3).	Paper or Fibre Insulated Cables. *Current.* Maximum Current Permissible.	Paper or Fibre Insulated Cables. *Volts Drop.* Approximate Total Length in Circuit (Lead and Return) for 1-volt Drop (Col. 4).	Minimum Insulation Resistance of 1 Mile in Megohms at 60° F. Vulcanised Rubber. Up to 250 volts.	Minimum Insulation Resistance of 1 Mile in Megohms at 60° F. Vulcanised Rubber. Up to 650 volts.	Minimum Insulation Resistance of 1 Mile in Megohms at 60° F. *Paper or Fibre* (Class B).	*Resistance.* Conductor Resistance in Standard Ohms per 1,000 yds. at 60° F.	Minimum Radial Thickness. Vulcanised Rubber. Up to 250 volts.	Minimum Radial Thickness. Vulcanised Rubber. Up to 660 volts.	Minimum Radial Thickness. *Paper or Fibre.* (Class B). Up to 660 volts.	Minimum Radial Thickness. *Lead Sheath.* On Paper or Jute Cables.
1.	2.	3.*	3a.	4.*	4a.	5.	6.	7.	8.	9.	10.	11.	12.
Inches.	Sq. In.	Amp.	Feet.	Amp.	Feet.	Megs.	Megs.	Megs.	Ohms.	Inches.	Inches.	Inches.	Inches
1/·036	0·0010	4·1	31	4·1	31	2,000	5,000	For conductors smaller than 7/·064", the insulation resistance must not be less than 140 megohms.	23·59	0·034	0·055	—	—
1/·044	0·0015	6·1	31	6·1	31	2,000	5,000		15·79	0·034	0·055	—	—
3/·029	0·0020	7·8	31	7·8	31	1,250	4,500		12·36	0·036	0·056	—	—
3/·036	0·0030	12·0	31	12·0	31	1,250	4,500		8·019	0·038	0·057	—	—
1/·064	0·0030	12·9	31	12·9	31	2,000	5,000		7·463	0·036	0·057	—	—
7/·029	0·0045	18·2	31	18·2	31	1,250	4,500		5·281	0·039	0·058	—	—
7/·036	0·0070	24	34	28·2	31	900	4,000		3·427	0·041	0·059	0·080	0·060
7/·044	0·0100	31	39	42	31	900	4,000		2·294	0·043	0·060	0·080	0·060
7/·052	0·0145	37	46	57	31	900	4,000		1·643	0·046	0·061	0·080	0·060
7/·064	0·0225	46	56	75	33	900	3,500	140	1·084	0·049	0·062	0·080	0·060
19/·052	0·0400	64	72	104	42	750	3,000	120	0·6063	0·056	0·063	0·080	0·060
19/·064	0·0600	83	84	135	49	750	3,000	110	0·4002	0·062	0·065	0·080	0·070

19/·072	0·0750	97	91	157	53	600	3,000	110	0·3162	0·066	0·066	0·080	0·070
19/·083	0·1000	118	99	191	58	600	3,000	100	0·2380	0·072	0·072	0·080	0·070
37/·064	0·1200	130	105	210	61	600	3,000	90	0·2056	0·075	0·075	0·080	0·070
37/·072	0·1500	152	114	246	66	600	3,000	90	0·1625	0·080	0·080	0·080	0·070
37/·083	0·2000	184	125	296	73	600	2,500	90	0·1223	0·088	0·088	0·080	0·070
37/·093	0·2500	214	135	343	79	600	2,500	80	0·09738	0·095	0·095	0·090	0·080
37/·103	0·3000	240	147	385	87	600	2,500	80	0·07939	0·102	0·102	0·090	0·080
61/·093	0·4000	288	165	464	97	600	2,500	80	0·05908	0·114	0·114	0·100	0·090
61/·103	0·5000	332	175	540	102	600	2,500	80	0·04816	0·121	0·121	0·100	0·090
91/·093	0·6000	384	184	624	107	600	2,500	80	0·03961	0·125	0·125	0·100	0·100
91/·103	0·7500	461	188	738	111	600	2,500	70	0·03229	0·131	0·131	0·110	0·100
127/·103	1·0000	595	204	932	123	600	2,500	70	0·02314	0·141	0·141	0·110	0·110

The above Table applies to single cables run in pairs and touching one another, and refers to situations where the maximum temperature of the air does not exceed 80° F. (26·7° C.).* The figures in columns 3, 3*a*, 4, and 4*a* have been supplied by the National Physical Laboratory, those in columns 3 and 4 are the currents corresponding, in the case of rubber-insulated cables, to a rise in temperature of 20° F., and, in the case of paper-insulated cables, of 50° F. above that of the surrounding air. The lengths in circuit given in columns 3*a* and 4*a* when working at the currents given in columns 3 and 4 are calculated on the assumption that the temperature of the cable will be 100° F. in the case of rubber insulation and 130° F. in the case of paper insulation.

* The figures in columns 3 and 4 may be multiplied by the following constants for the classes of cable shown: Concentric, 0·93; 3-core, 0·88; 4-core, 0·82.

Note—In lighting circuits where the determining factor is the drop in volts (Rule 40), the maximum currents may be less than those shown in columns 3 and 4.

[Rule 40 states that for lighting circuits the permissible drop in volts under ordinary conditions must not exceed 2% PLUS a constant allowance of 1 volt; *see* Table, cols. 3*a* and 4*a*.]

Mechanical and Weather Protection.—Small wires and cables are protected by a *braiding* of plaited or woven cotton, cords, metal wires or leather thongs, according to service. *Taping* may be used to resist abrasion, carry waterproof compound, or as a bedding for armour. A *serving* of impregnated string or cord serves the same general purpose and is more flexible, especially where a considerable thickness is concerned. Fibrous coverings are *compounded* with tarry or bituminous composition as a protective filling. *Lead sheathing* is the usual waterproof covering for paper insulated cables. Compounded tape or paper protects lead from corrosion by water or soil; in severe cases, the cable may be laid solid in bitumen. *Bitumen sheathing* may be used in place of lead, especially where the latter would be subject to electrolytic corrosion; the sheath may be taped and braided or served and armoured. *Tough rubber sheathing*, or cab-tyre sheathing (C.T.S.) is a compound composed of equal proportions of rubber and siliceous material, applied under pressure and then vulcanised. The sheathing should not be depended upon for any insulating value, but will stand very rough usage and is unaffected by moisture, oil, fumes, acid and any reasonable degree of heat. The covering is flexible and is generally applied over flexible rubber cables. *Armour* consists of one or two layers of galvanised steel wire, tape or specially formed locking strips. Tar-soaked yarn or jute may be used to protect the armour from abrasion; and jute serving beneath the armour protects lead or bitumen from pinching. A *leather jacket* laced in place, is often used in mining practice. Where armour is used to carry return current it should be left bare and thoroughly earthed; if imperfectly insulated it may be a source of grave danger, possibly at some point remote from a fault.

Methods of Supporting and Laying.—Bare conductors may be suspended overhead on pin-supported petticoat insulators or by series of link or disc insulators; or they may be strained taut in underground culverts and supported intermediately by insulating bridges. The latter system gives low insulation resistance, the conductors are exposed to corrosion and flood; and electro-magnetic forces may cause buckling and short circuits.

The lay-out of overhead lines is governed by the voltage between lines and by the type of supporting structure employed and the distance between supports. Where suspension insulators are used, the possible swing of the conductors must be allowed for when determining their spacing, and in all cases the electrical characteristics of the circuit and the mechanical design of the lines and their supporting structures must receive very careful attention (*see* Transmission Line Calculations).

Insulated cable may be run in wooden casing (with or without filling material according to circumstances); tubes, pipes, or culverts; or exposed and supported by insulators, leather thongs, or adjustable metal clips fixed on walls or poles; or they may be buried directly in the earth. Much depends on circumstances and upon the positions chosen for the circuits, and, providing due regard is paid to the possible leakage and shock, the question is largely one of cost, convenience, and the pressure employed. So far as possible, circuits should be arranged and divided so that each may be tested separately and disconnected, in case of need, with a minimum of inconvenience. Cheap and inferior cable materials and erection methods tend to leakage, waste, danger, and breakdown.

Direct Laying.—Cables laid direct in the earth should be armoured, overlaid with tarred jute, and protected by tiles or a dry strip of wood or steel from pick blows. Sand or dry earth is innocuous, but cinders, limestone soils or soils containing manure, garbage, or chemical refuse will attack lead and steel, and, in such cases, cables should certainly be laid solid.

Solid System.—The cable is laid on earthenware or wooden-bridge pieces in a trough of earthenware or impregnated wood, which is then filled in with Trinidad bitumen or good pitch and covered with tiles or planking. So long as care is taken to exclude rain and moisture, during the laying operation, no better system could be wished for, providing the cable has not subsequently been disturbed. In Glasgow excellent results have been obtained with a mixture of 8–10 gallons of asphalt oil to 1 ton of pitch. The low melting-point of such a mixture reduces the risk of damage to bitumen sheathing during filling, but may, in some cases, lead to trouble by leakage or creeping in lengths of inclined or strained troughing. Cables laid in bitumen or pitch must be kept away from steam or hot-water pipes; so, in general, should all other electrical conductors. The solid system of laying is the one most frequently adopted in central stations in the United Kingdom.

Pipe or Conduit Systems.—Cables are drawn into cast, wrought, or riveted sheet-iron pipes; into earthenware pipes; or into tunnels in earthenware blocks, or in reinforced cement blocks built up *in situ*. Generally the cables are simply surrounded by air, which (particularly in "banks" of conduits) has a heat insulating effect and reduces seriously the carrying capacity of the cables for given temperature rise. Conduit systems make possible with minimum trouble the substitution of one cable for another, or the laying of additional cables in the same or spare ducts, but the system on the whole is costly

and inflexible; and the life of cables is certainly not extended as compared with that realised where the solid system is used. Earthenware multi-duct blocks are generally employed in conduit systems in this country; cast-iron pipes in 15 or 20% of the total number of cables concerned; and wrought-iron in most other cases. Fibre conduit and concrete conduits formed *in situ* are comparatively little used in this country; both deserve to be more freely employed. The Brooke *semi-solid system* uses wrought-iron tubes filled with a viscous oil liquid at 300° F.

Hints on Laying Cables.—*Employ first-class materials and methods, and apply freely to manufacturers for advice.* Examine the soil in which the cable is to be laid; if it is corrosive in effect do not lay cables direct; if it is yielding, allow for subsidences. Asphalt troughing is very flexible and is waterproof. Make provision for the worst possible conditions which can be foreseen. Remember that, though certain special cables will withstand practically any treatment, there is no object in being deliberately careless. Paper-insulated cables *must* be kept dry; cut-off ends must be sealed off at the earliest possible moment, a plumbed lead cap or "wiped" joint being made on lead-covered cables and a suitable waterproof tape being used on bitumen-sheathed paper-insulated cables. Short exposure to a damp atmosphere will ruin any cable employing hygroscopic insulating material. Properly designed dividing boxes and suitable filling material, suitably applied, must be used to prevent moisture trouble at joints in paper-insulated cables. Rubber cables will generally stand any reasonably rough treatment without damage; lead or bitumen cables must be handled as gently as possible; bitumen is "short" in cold weather. Wooden bridges in solid-laid systems must be thoroughly impregnated with bitumen, and should always be regarded as potential means of ingress of moisture. Mandrels should be used at cemented joints in conduits to prevent formation of burrs capable of damaging the cables. Conduits should slope 1 or more in 100 to secure drainage; draw-wires laid with the conduit generally corrode before they are required; it is preferable to depend on "rodding" and place draw-boxes from 70 yd. apart on level (less on curves) to 100–200 yd. apart on gradients. Manholes should be thoroughly drained and ventilated, liberally proportioned as to width and depth, and at least three times as long as the longest joint to be accommodated. Cables should be thoroughly lubricated with vaseline or special grease before drawing in; chafing on sharp or rough edges must be avoided; a steady pull (as exerted by a crab winch) is preferable to the more picturesque "He-e-ave" method. Cable should pass from drum to conduit in one smooth sweep, and work should be carried out in that direction which will afford most assistance from down gradients.

Standard Data, Definitions and Conventions for Copper Conductors (British Engineering Standards Association Specification No. 7, 1919).—*Standards of Resistance for Standard Annealed Copper.*—At 20° C. the resistance of a wire 1 metre long and 1 sq. mm. section (uniform) is 1/58 ohm (0·017241 ohm). At 20° C. the resistance of a wire of uniform section, 1 metre long, and weighing 1 gramme is 0·15328 ohm. At 60° F. the resistance of a solid conductor 1000 yd. long and 1 sq. in. section (uniform) is 0·0240079 ohm. (Note.—The resistance of hard drawn copper conductors is about 3% higher than for standard annealed copper, the exact figure varying with the size of the wire and with the elongation at the breaking load.) *Density of Standard Annealed Copper.*—At 20° C., 8·89 grm. per cu. cm. At 60° F., density = 8·892015; and weight per cu. ft. = 555·1108 lb. *Temperature Coefficient of Resistance.*—"Constant mass" temperature coefficient of resistance measured between two potential points rigidly fixed to the wire is 0·00393 per degree Cent. at 20° C.; and 0·0022221 per degree Fahr. at 60° F. *Coefficient of Linear Expansion.*—Between 60° F. (15·6° C.) and 68° F. (20° C.), 0·00000944 per 1° F. (0·000017 per 1° C.). *Tolerance.*—The following tolerances are permitted on the standard weight and resistance of conductors.

Conductors	Tolerance Plus or Minus. Per cent.	
	Weight.	Resistance.
Solid (and annular of concentric cables)—		
Plain	3	3
Tinned, 0·036 in. diameter and over	3	4
Tinned, below 0·036 in. diameter	3	5
Stranded—		
Plain	2	2
Tinned, 0·036 in. diameter and over	2	3
Tinned, below 0·036 in. diameter	2	4

Allowance for Lay.—An increase of 2% in the length of each wire in a stranded conductor (except the centre wire) is assumed to allow for the laying up of the wires. The resistance is calculated on the assumption that the individual wires are practically insulated from each other, and the area of the stranded conductor is taken as the area of the solid wire, which has the same resistance as the stranded conductor. An increase of 2% on the resistance of a straight core of the same length is taken in the case of cores in multicore cables to allow for the laying up of cores.

WIRING SYSTEMS AND METHODS.

The following notes give as full treatment as possible, in the space available, concerning the features, merits and methods of various wiring systems. Details of wiring accessories, etc., will be found in manufacturers' catalogues. Reference may be made to "Lighting Circuits and Switching" for information on that subject.

The primary object of any wiring system is the electrical service which it renders, and the primary requirement is electrical safety; in addition to that immunity from mechanical injury and damage by weather or fumes, etc., must be considered, and the appearance of the wiring is often an important consideration. Wiring may be bare or insulated; insulated wires may be mounted directly on walls, or on cleats, or laid in casing or conduit: each system is discussed below.

Conductors.—For wiring fittings the smallest permissible section is that of No. 20 S.W.G. (*i. e.* 0·001 sq. in. equal to 3/24 S.W.G. or 1/0·036 in.). For all other purposes the minimum section is that of No. 18 S.W.G. (*i. e.* 0·0018 sq. in., the nearest size in the new standards being 3/·029 in., having 0·0020 sq. in. section). Subject to these minima and subject to the carrying capacities specified by the new I.E.E. Wiring Table (pp. 162–163) the minimum size of conductor for lighting circuits is determined by the permissible voltage drop, which is 2% plus a constant allowance of 1 volt. In power and heating circuits the limiting factor is the temperature rise of the conductors, which should not exceed 20° F. The conductivity of the conductors should comply with the B.E.S.A. Specification (*see* p. 167) All insulated copper conductors larger than No. 16 S.W.G. (0·0032 sq. in., nearest new standard size being 1/·064 in.) should be stranded. Twin core conductors may be used if preferred. Concentric twin conductors may be used, but this is only advantageous in house wiring if the "outer" be a bare earthed sheathing. The following table is useful as showing the new standard sizes of conductors compared with S.W.G. sizes; also the approximate overall diameters of braided conductors, 600 and 2500 megohm grades.

Insulation.—Though simpler insulation may sometimes be satisfactory for very dry situations and for pressures up to 50 or 100 volts, the covering on insulated conductors, other than flexibles, for use in this country should be either vulcanised rubber, or impregnated paper or fibre. Where vulcanised rubber is used it is only necessary to provide mechanical protection for the conductor (by metal conduit, wood casing, tough rubber compound, or armouring). Where paper or fibre is used, it is necessary to provide a waterproof sheath (usually of lead). Minimum radial thicknesses for insulation and for lead

S.W.G. AND NEW STANDARD WIRE SIZES; AND OVERALL DIAMETERS OF BRAIDED CONDUCTORS.

S.W.G. No.	New Standard No. and Diam. of Wires in Inches.	Nominal Area of Conductor. Sq. In. *	Approx. Overall Diam. in Inches (Braided 600 and 2500 Megohm Grades.)
1/20	1/·036	·0010	·165
—	1/·044	·0015	—
1/18	—	·0018	·179
3/22	—	·0018	·193
—	3/·029	·0020	—
7/25	—	·0022	·193
3/20	3/·036	·0030	·215
7/23	—	·0031	·207
1/16	1/·064	·0032(0)	·197
7/22	—	·0042	·221
—	7/·029	·0045	—
7/21½	—	·0049	·229
7/20	7/·036	·0070	·294
7/19	—	·0086	·308
—	7/·044	·0100	—
7/18	—	·0125	·336
—	7/·052	·0145	—
7/17	—	·0170	·366
7/16	7/·064	·0221(5)	·394
19/18	—	·0338	·452
7/14	—	·0346	·452
—	19/·052	·0400	—
19/17	—	·0459	·500
19/16	19/·064	·0600	·548
19/15	19/·072	·0750	·596
19/14	—	·0937	·644
—	19/·083	·1000	—
37/16	—	·1168	·702
—	37/·064	·1200	—
19/13	—	·1250	·716
37/15	37/·072	·1500	·768
37/14	—	·1824	·844
37/·083	37/·083	·2000	—
37/·092	37/·093	·2500	·964
37/·104	37/·103	·3000	1·066
61/·092	61/·093	·4000	1·186
61/·104	61/·103	·5000	1·330
61/·112	91/·093	·6000	—
91/·101	91/·103	·7500	—
127/·101	127/·103	1·0000	—

* The bracketed numbers in this column are the fourth decimal place in the areas of the new standard when this differs from the old standard; *e.g.* ·0032(0) means old standard 0·0032, new standard 0·0030.

sheathing are given in the I.E.E. Wiring Table (p. 162). Insulating material containing sulphur must not be in direct contact with copper wires.

Flexibles.—"Flex" is necessarily used in pendants and other special fittings, but it is not to be recommended, and should not be used for general wiring, except for temporary purposes and pressures below 100 volts. It is worth using strong "workshop" flex for vacuum cleaners, etc. The new British Standards for flexible cords are as follows :—

Nominal Area.	No. of Wires (each of 0·0076″ diam.).	Resistance per 1000 yd. at 60° F.		
		Standard.	Maximum for Plain Wires.	Maximum for Tinned Wires.
Sq. In.		Ohms.	Ohms.	Ohms.
0·0006	14	39·7	40·5	41·3
0·0010	23	24·2	24·6	25·1
0·0017	40	13·9	14·2	14·4
0·0030	70	7·94	8·10	8·26
0·0048	110	5·05	5·15	5·25
0·0070	162	3·43	3·50	3·57

General Precautions.—Whenever wiring is to be installed, fire insurance and electricity supply companies should be advised, so that their special requirements (if any) may be met. For the rest, the I.E.E. Wiring Rules may be followed, and a perusal of these gives a good general idea of modern wiring methods and systems. Very special precautions must always be observed wherever there is inflammable or explosive dust or vapour; also in damp situations or where corrosive fumes are present. In domestic wiring, bathroom circuits and fittings must be installed very carefully, as the danger of leakage is particularly great, and shocks, even at the lowest voltage, may be fatal to a person bathing. Power and lighting circuits should be kept distinct (except as regards running small domestic motors from lighting sockets); the two sides of a 3-wire system should be kept well apart whenever possible in buildings. It pays to supervise erection very carefully; to see that the conductors are not injured during drawing-in or other operation; and to see that overcrowding is avoided, and that there are no roughnesses in conduit or fittings, etc. Leading-through tubes of porcelain or stout metal conduit suitably bushed are necessary at walls and floors. All metal sheathing, whether part of the conductor or not, must be electrically continuous, bonded across all switch-boxes, etc. (and to them if of metal), and connected to earth. Clips should be of the same metal as conduit or metal sheathing with which they are in contact.

Bunching.—"Bunching" must be done in A.C. circuits where the conductors are in metal casing: D.C. conductors of opposite polarity may be bunched in metal conduit, or if protected by a covering of tough rubber compound, but in non-metallic or no enclosure they may only be bunched if of the same polarity and free from joints; it is bad practice to bunch separate circuits at all extensively.

Distribution Boards.—Accessibility of all parts of a wiring system is desirable; liberal use should be made of branch distribution boards; and fuses should not be scattered about the installation save in exceptional circumstances. Switch and distribution boards should be mounted in a dry position free from fumes, etc., and well away from inflammable material. The base of the board should be insulating, moisture-proof and non-inflammable. Connections should be proportioned liberally and be made easily accessible. Circuits should be labelled clearly. Live parts should be spaced well apart; and separating partitions used where there is risk of arcing. Protection must be provided against fire or other injury due to metal from fuses.

Joints.—All joints are a source of weakness. Where they cannot be avoided they must be accessible, mechanically and electrically sound, and soldered (except where flex is connected to solid conductors, in which case a screwed connection must be provided in a junction box). Great care should be taken to insulate joints thoroughly and to exclude moisture. Thimbles should be used to connect conductors larger than 7/18 S.W.G. (say 7/·044 in.) to terminals, except in the case of connections to consumers' meters for currents up to 100 amp. made in accordance with B.E.S.A. Specification No. 37. Where joints have to be made at fittings they must be made equal to the rest of the work in respect to conductivity and insulation. The cost of the extra length of wire and additional fittings required by the "looping-in" system of wiring is undoubtedly a good investment, because it practically eliminates joints and gives an installation of permanently high electrical conductivity and insulation resistance.

Bare Conductors should only be used as a matter of necessity (*e.g.* for carrying current to travelling cranes, etc.). They are convenient for such special purposes as battery connections, leads to electric furnaces, and so on; when of large section their rigidity adds materially to safety. They should be used only where inaccessible to unauthorised persons; they have no application in house wiring; and their use should always be advised to the insurance company, or policies may be rendered invalid. Provision must be made against short circuit between wires by

displacement, by breakage of one insulator, by metal articles falling across them, or by collector gear. Bare wires should be kept strained when not rigid in themselves; earthed guard wires provided where necessary; and wires suitably painted if desirable (so long as they are not used as trolley wires). A fuse and isolating switch should be placed in each conductor. The conductors must be mounted on insulators or otherwise insulated, and spaced from each other and from walls, as in the cleated system, but with larger clearances. If the bare conductor be displaced from any insulator it should not be able to come into contact with another bare conductor, with the building-wall, or with structural or other metal work. Double insulation and proper straining gear must be provided at strain points. If the bare wiring is exposed to lightning, each conductor must be provided with lightning arrester. Bare conductors are preferable for end- and regulating-cell connections in accumulator installations.

Uncased Wiring.—In this and all the undermentioned systems, insulated conductors must be used. Wiring mounted directly on walls should be metal sheathed and secured by special clips, *never* by staples. Unsheathed or metal sheathed wiring should not be used on damp walls; C.T.S. wiring is best for such and other unfavourable situations. Conductors protected by steel armouring or by brass or copper (or equivalent) sheathing may be used without conduit or wood casing provided that the armouring or sheathing be earthed. Unarmoured conductors with a sheathing containing not less than 95% pure lead (and of thickness complying with B.E.S.A. standards) may be used provided that they are protected by casing or conduit where exposed to mechanical injury, and by metal conduit where buried in cement or brickwork, etc. Such conductors must be supported (at intervals close enough to prevent sagging) by clips, saddles or clamps; these must not injure the sheathing and may not be of copper. In vertical runs not easily accessible the supports may be 10 ft. apart if each one clamps the conductor securely so as to carry the weight of the span below. At changes of direction the wire should be taken over a rounded support of at least six times its own diameter. Such conductors may not come in contact with damp brickwork or plaster, and the sheathing must be earthed and bonded throughout, the resistance of the sheathing between any two points in the finished installation not exceeding 2 ohms. Unarmoured and unsheathed conductors may be used without casing, subject to the general conditions laid down in the next paragraph.

Cleat System.—When open wiring can be run without special risk of mechanical injury or attack by steam or fumes it is best mounted on cleats. The system is simple and cheap, but not suitable where appearance is a primary consideration. Porcelain

blocks are screwed to wall plugs at intervals of 3 ft. or so, and these, with their grooved cover caps (1, 2 or 3 grooves), space the conductors definitely from each other, and from the wall and pipes, etc. Good cable must be used, and it should be strained tightly when erecting. Dust collects on the wires and is projected on to the wall behind the negative wire by electrostatic action; after a time dust and slackness, particularly at corners, result in untidy appearance. Cleated wiring should be as far as possible in sight and never out of easy deliberate reach; at the same time it must be out of harm's way and should not be run unprotected within 5 to 7 ft. of the floor. The distance between wires should never be less than 1 in. in branch circuits; main leads in 200–250 volt circuits should be about 2½ in. centre to centre and for higher pressures should be 4 in. apart and not less than 1 in. from the wall. Twin conductors may be cleat supported as such, without separating them; and twin flex may be used for temporary purposes and in specially favourable positions on button insulators slipped between the two wires at intervals. I.E.E. rules permit single core conductors to be run unspaced in cleats, up to 6 amp. per wire, but it is better to use a double or triple groove cleat as required. Wherever uncased, unarmoured conductors without metal or tough-rubber covering, pass through walls or under floors or partitions, etc., they should be protected by wood casing or metal conduit, the open ends of the latter being suitably bushed. Fairly closely fitting porcelain tubes are recommended for carrying conductors through division walls.

Wood Casing has not the fire-proofness of steel conduit, but if properly installed it is quite safe and reliable. It is moderately cheap, and can be made to harmonise with any surroundings, particularly if dummy casing is used wherever required to prevent an unbalanced appearance. It pays to use a substantial casing of good timber and to fix it by screws along the edges (not merely up the centre). Wires of opposite polarity should not be bunched in wood casing. The system is best confined to dry situations, and casing should not be buried in plaster. If the situation is at all damp, the casing should be painted and mounted on porcelain spacing pieces and impregnated wooden wall plugs; the run should be clear of drip from pipes or other cold surfaces. The grooves should be painted if lead sheathed conductors are to be installed, because lead is attacked by acetic acid. No sharp corners should be permitted in the wiring grooves at bends; joints in casing and cover strip should be staggered. It is worth taking special care at joints and cross-overs, etc., since botched carpentry is ugly and involves risk of injury to wiring. Cross-overs should be bridged; if a flush finish is desired, the casing groove must be large enough to

avoid deformation of the conductors, and the latter should be separated by mica strips. Wood casing is light and easy to manipulate; its insulating nature is an advantage, but is only to be regarded as an "extra," *i. e.* it must not be reckoned as part of the normal insulation of the system. By removing the cover strips, the whole of the wiring can easily be examined at any time, and extensions are made easily. The disadvantages are that the system is neither damp- nor fire-proof, and it is easily damaged mechanically. There is considerable risk of nails being driven in wood casing which is concealed or camouflaged.

Conduit System.—Though the most costly to install, that system is safest and best which places the conductors inside a network of metal tubes. "Close joint" conduit is not to be recommended. The joint should be brazed or welded, or solid drawn tubing should be used. The tubing is generally of steel, but may be of tinned brass if it is wished to solder all joints. It is worth using substantial conduit and fittings. Since it is the external diameter of conduit which is standardised, heavy gauge or insulated conduit has smaller wiring capacity than lighter gauge tubing. A variety of finishes are available for steel conduit: sherardising, galvanising and enamelling being commonest. Enamelled finish is usual; the enamel should neither scale nor chip off when bent or struck. The inside of the conduit may be insulated by paper or other material, which should be unaffected by moisture or heat (up to 212° F. or so), fixed securely to the conduit, incapable of damaging the wires mechanicall or chemically, and itself uninjured by drawing-in wires. Conductors may be threaded into conduit when erecting the latter, but it is generally more convenient to draw them in after completing the conduit; there is then less liability to injure the wires, but a larger size of conduit must be used and should not be overcrowded. It is good policy to use plenty of inspection boxes; certainly there should not be more than four 90° bends (or their equivalent) between adjacent boxes. The latter should be long, to save sharp bends and risk of cutting in drawing-in. Bends should be of large radius, preferably not less than 3 in. inside radius. Large conductors can be pushed through the conduit after erection. The ends of wires should be bound together and taped over to form a smooth snout which will not catch in joints and bends. French chalk is a useful lubricant; grease or oil must never be used. The complete conduit system can be erected in the skeleton of a new building and then plugged till needed. A steel draw wire (say $\frac{3}{16}$ in. $\times \frac{1}{32}$ in. steel tape or a round wire) may be threaded through the conduit during erection; drawing-in will then cost very little. Whenever a wire is withdrawn for repair it should be used to pull in a pilot wire for its replacement. Conduit may

be buried in plaster, in fact it is the best and safest system for completely concealing electric wiring. From first principles one would expect it to be best to seal a conduit system as perfectly as possible in damp situations, but it is practically impossible to ensure that a system of conduit and switch boxes, etc., is *absolutely* sealed; the result is that moisture is drawn in by contraction following thermal expansion, but only a fraction of the moisture is expelled during the next expansion, so that moisture gradually accumulates if the whole system be not hermetically sealed. Experience in the tropics shows that it is best to ventilate the conduit thoroughly, placing a drain outlet wherever moisture would otherwise collect. Insects may be kept out by gauze covers. Electrical continuity is imperative throughout any conduit system; it is secured automatically by screw joints, but special continuity pins or grips are necessary with slip joints.

Steel conduit is equally suitable for surface or concealed (buried) installation, and it is, of all wiring systems, the one least liable to mechanical damage. The runs of buried conduit should be indicated on the surface whenever possible. If the metal be protected by a suitable covering it is rust-proof and unaffected by acids and alkalis. Light rolled steel tubes and malleable cast-iron fittings were first marketed by the Simplex Company, and from the introduction of conduits in this form their use has extended year by year. The standard types of conduit are: *Light Gauge Unscrewed*—Close joint, Brazed and Solid drawn. *Heavy Gauge Screwed*—Welded, Brazed and Solid drawn. All steel conduits and their accessories should comply with the B.E.S.A. Specification No. 31. All open ends of conduit must be bushed to prevent abrasion of wires, and, with the exception of isolated single lengths of enamelled conduit, all conduit must be earthed.

Earthing.—The earth connection should be of copper, not less than No. 14 S.W.G. (say 7/·036 in.) or 0·005 sq. in. for every 50 amp. working current in the case of heavy current circuits. If satisfactory earth connection cannot be obtained to a water-pipe, use special earth plates, 18 in. square, placed upright and surrounded by 12 in. of broken coke in moist soil. (*See also* chapter on Earthing.)

Wiring Capacity of Conduit.—The accompanying table shows the wiring capacity of light and heavy gauge Simplex conduits. The nearest new standard sizes of wire corresponding to the S.W.G. sizes have been added to the table to increase its value. It will be noted that the table does not contemplate the placing of more than six conductors in the same conduit. A useful rule for determining the size of conduit in cases not covered

WIRING CAPACITY OF LIGHT AND HEAVY GAUGE CONDUITS.

(BASED ON RECOMMENDATIONS BY SIMPLEX CONDUITS, LTD.)

Size of Conductor.		Current Carrying Capacity (I.E.E. Rules). Amps.	Overall Diameter of Conductor.	Maximum Number of Wires in—														
				Light Gauge Conduit, External Diameter.							Heavy Gauge Conduit, External Diameter.							
S.W.G. (Old Standard).	Nearest New Standard Size.			½″	⅝″	¾″	1″	1¼″	1½″	2″	½″	⅝″	¾″	1″	1¼″	1½″	2″	2½″
	Inches.		Inches.															
1/18	1/·044	6·1	·179	2	4	6	–	–	–	–	2	4	5	–	–	–	–	–
3/22	3/·029	7·8	·193	1	3	5	–	–	–	–	1	2	3	6	–	–	–	–
3/20	3/·036	12·0	·215	–	2	4	–	–	–	–	–	2	3	6	–	–	–	–
7/22	7/·029	18·2	·221	–	2	4	–	–	–	–	–	1	2	5	–	–	–	–
7/21½	7/·029	18·2	·229	–	1	3	6	–	–	–	–	–	2	4	–	–	–	–
7/20	7/·036	24·0	·294	–	–	1	4	6	–	–	–	–	1	3	6	–	–	–
7/18	7/·052	37·0	·336	–	–	–	3	5	–	–	–	–	–	3	5	6	–	–
7/16	7/·064	46·0	·394	–	–	–	2	4	6	–	–	–	–	2	3	4	–	–
7/14	—	60 (O.S.)	·452	–	–	–	1	3	4	5	–	–	–	1	2	3	6	–
19/18	—	59 (O.S.)	·452	–	–	–	–	3	4	5	–	–	–	–	2	3	6	–
19/17	19/·052	64	·500	–	–	–	–	1	3	5	–	–	–	–	1	2	4	–
19/16	19/·064	83	·548	–	–	–	–	–	3	5	–	–	–	–	–	2	4	–
19/15	19/·072	97	·596	–	–	–	–	–	2	4	–	–	–	–	–	1	3	–
19/14	19/·083	118	·644	–	–	–	–	–	2	4	–	–	–	–	–	–	3	5
37/16	37/·064	130	·702	–	–	–	–	–	1	3	–	–	–	–	–	–	3	4
37/14	—	172 (O.S.)	·844	–	–	–	–	–	–	2	–	–	–	–	–	–	1	3

NOTE.—The overall diameters of conductors given above refer to braided cables 600 and 2500 megohm grade. The wiring capacity of conduit varies with the flexibility of the cable and with the nature of the run of the conduit. The wiring capacity is slightly lower for drawing-in than for threading-in. The above table is generally a safe guide for drawing-in, but it is inadvisable to attempt to wire the conduits to their full capacity, especially on difficult runs.

by the table is: The overall section of the cable should not exceed (as a percentage of the internal section of the conduit)—56% in the case of a single conductor; 32% for two conductors; 42% for three conductors; 40% for four, and 37% for more than four conductors.

Example.—Required the size of conduit for five 7/23 S.W.G. cables. The overall diameter of a 7/23 braided cable is about 0·207 in. (*see* Table above), and the section of five such cables is 5 × ·0336 = 0·168 sq. in. This must be not more than 37% of the internal section of the conduit, which must, therefore, be not less than 0·168/0·37 = 0·455 sq. in., *i. e.* not less than 0·76 in. diameter, or say 7/8 in. outside diameter. This, it will be seen, agrees with the Simplex table. The principal use of the above rule is for estimating the size of conduit for combinations of different sizes of wires.

Metal-Sheathed Wiring.—Various "proprietary" conductors come under this heading, the sheathing being of lead, lead alloy, or copper (lead being drawn or squirted on, and copper being wound on in strip form, and either sweated together or lead sheathed). A copper sheathing may be used as return conductor for a concentric system, but must not be used as the neutral of a 3-wire D.C. system. In any case, the sheathing must be electrically continuous and connected to earth, otherwise there is risk of shock and electrolytic action. Metal-sheathed wiring is neat, small and easily hidden. It may be painted if desired, or laid solid in plaster of Paris, but should not touch ordinary plaster mortar or damp brickwork. Round wire or other steel *armouring* may be used as a mechanica protection on wiring conductors.

Earthed Concentric Wiring.—An ordinary concentric cable (with two insulated cores) offers no advantage for house wiring, but "earthed-concentric" wiring is cheaper than the use of two insulated conductors. The outer conductor is bare and must be earthed, hence the system is only permissible where private generating plant is used, where supply is taken from A.C. mains through *double wound* transformers, or where the use of earthed concentric system is approved by the Board of Trade. Where used at all, this system must be carried right up to the end of each "point," *i. e.* to where the fittings-flex is connected. No switch or fuse must be placed in the "outer" of an earthed concentric system; this, like any other earthed conductor in a wiring system, must be continuous throughout and connected permanently to earth. The drop in volts on the external conductor when the maximum current is in use must not exceed

7 volts from the point of earthing to the furthest lamp on the system. Within any particular building the permissible drop in the lighting circuit is 2% plus 1 volt.

Special Wiring Systems.—The following notes outline the principal proprietary wiring systems, all of which comes under one or other of the above headings. In every case the manufacturers supply special fittings, accessories, etc., which should be used in order to obtain the best results. *Steel Conduit.*—Simplex, Geekoduct and Anchor conduits are probably the best known; the distinctive features lie mainly in the mechanical details of the accessories. *Kalkos.*—This is a conduit system using light gauge drawn brass tube tinned inside and out. Slip socket joints are provided, these being soldered *in situ* to give a hermetic seal and electrical conductivity. The conduit may be used as the earthed conductor of a concentric wiring scheme. *Stannos Wires.*—Rubber insulated wires are covered with paper and lapped over with tinned copper strip which is converted into a homogeneous sheath by a special process. The sheath is moisture-proof, electrically continuous, and affords mechanical protection to the wire. It is semi-flexible, and may be used as the return conductor of a concentric wiring installation. The wire may be used alone or in conjunction with Kalkos conduit. *Lead-covered wire* is moisture-proof in itself, but should not come into contact with damp brickwork, plaster or unpainted wood. Special ferrules are supplied to ensure electrical continuity of the sheathing at joints. The sheathing is readily attacked by leakage current, and must be electrically continuous and well earthed. *Henley System.*—Either two-core twin cable or concentric cable is used, the outer conductor in the latter case being a tinned copper tape wrapped spirally. In both cases a sheath of hard lead alloy is applied which is tough yet sufficiently flexible for easy erection. Special fittings are used to secure electrical continuity of the sheathing, but in the concentric cable it is the copper tape which is relied upon to carry the return current, this having a conductivity equal to that of the inner wire. *C.T.S. System.*—The conductor is protected mechanically by cab-tyre sheathing (or tough rubber compound) which is of great mechanical toughness and strength (without being inflexible), and will resist moisture, acids, alkalis, paint, etc. For most purposes the cable can be fixed directly on the wall by saddle clips without any special mechanical protection. This type of cable covers practically all conditions and requirements. Where conditions are very bad it should be used in conjunction with special fittings provided with semi-liquid seals to exclude fumes, etc., from connections.

LIGHTING CIRCUITS AND SWITCHING.

The immense number of lighting circuit connecting and switching systems now in use may be classified broadly into the following main groups :—(A) " On " and " off " control from one, two, three or more points. (B) " All," " part " and " off " control from one or a number of points. (C) Restricted, master switch, dim light and other special controls. Messrs. A. P. Lundberg & Sons have taken a prominent part in evolving lighting connections and tumbler switches to suit all possible require-

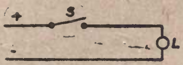


FIG. 34.

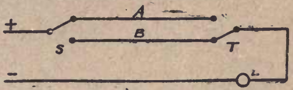


FIG. 35.

ments, and their trade publications rank as textbooks on the subject. To take full advantage of these connections requires the use of special switches, but for the sake of clearness ordinary single and two-way switches are shown wherever possible in Figs. 34–50.

A.—" *On* " *and* " *Off* " *Control. From one point.*—Fig. 34 represents this, the simplest possible system of lighting control; no explanation is necessary; no special switchgear is required.

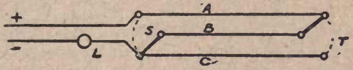


FIG. 36.

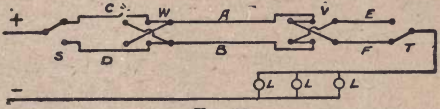


FIG. 37.

Where single pole isolation is insufficient, double pole switches must be used; if of the snap type, in which the " on " setting connects diagonally opposite terminals, the wiring connections must be correct, otherwise the switch will short circuit the mains when " on." *From two points.*—Fig. 35 represents this system of control. Two-way switches ST are used, and one of the two leads (or " strapping wires ") AB is necessarily " live " whatever the switch setting. In the case illustrated, the lamp is " off "; reversing the position of either switch completes the lamp circuit. Existing single point control can be converted to two point control by substituting a two-way switch S (Fig. 36) for the

existing switch, adding a second two-way switch T and connecting the two switches by triple flex ABC; the existing wiring need not be disturbed. *From three or more points.*—"On" and "off" control from four points is illustrated in Figs. 37, 38. In Fig. 37, the switches ST are of the two-way type, while VW are double pole change-over switches. In the setting shown, the lamps are "on"; reversing the setting of any one of the four switches opens the lamp circuit. The intermediate switches

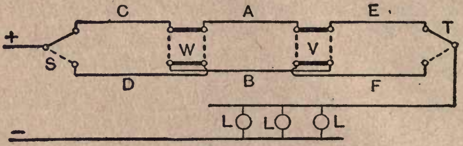


FIG. 38.

VW simply cross over the connections or AB to CD and EF, thus permitting a through "live" connection to be made from C or D to E or F at will. In place of each switch VW there may be used two two-way switches interconnected electrically as in Fig. 39 and having mechanically coupled knobs or switch arms *or*, as shown in Fig. 38, there may be used a special four-terminal intermediate switch giving the connections shown solid and dotted. Two wires enter and leave the intermediate switch in either case, so that where there are six contacts (Figs. 37, 39) four are terminals and two are change-over contacts.

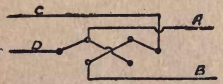


FIG. 39.

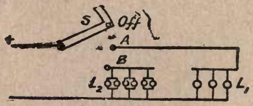


FIG. 40.

B.—"*All*," "*part*," *and* "*off*" *control.*—Fig. 40 illustrates a means of obtaining this control from one point. In the position shown, the switch arm S is "off." When S is on contact A, the lamps L_1, are lighted, and when S rests on contact B, as well as on A, both sets of lamps are in circuit. In a switch of the tumbler type the three settings "on," "off" and "part" may correspond to down, central and up settings of the knob. To obtain variable control from *two or more points*, use should be made of the special Lundberg switch illustrated diagrammatically in Figs. 41, A, B, C. Three knob positions, "up," "central" and "down," correspond to the connections shown. A three-position intermediate switch (Figs. 42, A, B, C) is combined with

two of the above switches to make possible lighting either of two groups of lamps (Fig. 43) from any one of the three switching stations. Whatever the setting of the other two switches, each switch connects *either* one set of lamps *or* the other (" restrictive " control) and has an " off " position. Alternative connections possible within the switches RT are shown in Fig. 41 and those within switch S in Fig. 42.

Although in Fig. 43 the switches give either of the two groups of lamps or " off," their function may be changed by utilising

FIG. 41.

FIG. 42.

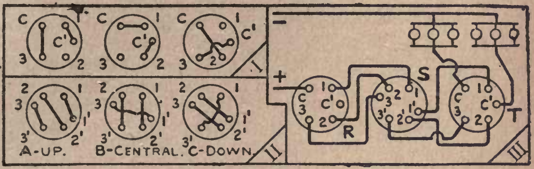


FIG. 43.

the vacant terminal of the switch R. By connecting this to the top left-hand terminal of switch T, we obtain the " all-part-off " control mentioned on the preceding page. Again, the positive main, Fig. 43, may be connected to the vacant terminal of R (as well as to its present terminal). An " either or both " control is then obtained, a separate switch being used for " on " and " off." It will be seen from Fig. 42 that each terminal 1, 2, 3 is connected in turn to each of the other three terminals (*i. e.* 1 to 1′ 2′ 3′; 2 to 2′ 3′ 1′; 3 to 3′ 1′ 2′); hence

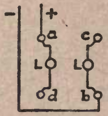


FIG. 44.

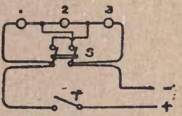


FIG. 45.

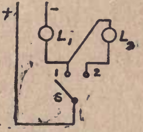


FIG. 46.

the switch is in effect three coupled three-way switches. As used in Fig. 43, it gives two live ways and an " off " position.

C.—*Miscellaneous Lighting Circuits. Dim Lighting Connections.*—Various " dimmer " switches have been marketed from time to time to permit dim illumination to be obtained where incandescent filament lamps are used. Most of these switches have been based on the principle of placing more or less resistance in series with the lamp. Current consumption is thus reduced, but the light obtained decreases much more rapidly. Any dimming arrangement is necessarily inefficient, but least loss is involved when a second lamp instead of a non-luminous resistance

is used for dimming purposes. This may be arranged as in Figs. 44–46. In Fig. 44 the lamps are in series when *c* is connected to *d*, and in parallel when *a* is connected to *c* and *b* to *d*; special two-way and off switches are available to affect either of these connections or to open the circuit. In Fig. 45 the lamps 1, 2, 3 are in series when S is "off," but in parallel when this coupled switch is "on"; the switch T opens or closes the circuit. Fig. 46 provides for one lamp at full brightness or two lamps in series. When the two-way-off switch S closes contact 1, L_1 burns brightly; when S closes 2, L_2 is placed in series with L_1. Series parallel control can be arranged from any desired number of points.

Limiting Control.—By using two- or multi-way switches with or without "off" positions, the maximum demand in the circuits concerned can be kept within predetermined limits. In the case represented by Fig. 47 two-point control is provided at AB. These switches control the general lighting LL. The two-way-off

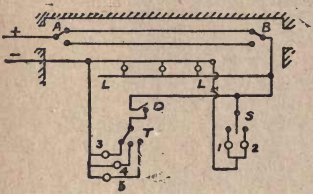


FIG. 47.

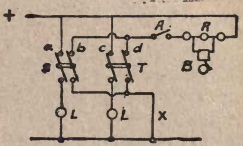


FIG. 48.

switch S permits either, but not both of the lamps 1, 2 to be used. The lamps 3, 4, 5 are in an inner chamber, and one, but one only, of these lamps is placed in the circuit by the door switch D; the selector switch T is of the three-way type.

Alarm and Pilot Circuits. Master Control.—In addition to the window, door and showcase type of burglar alarm described later, alarm bells or pilot lamps are often arranged in conjunction with lighting circuits (for burglar alarm or general supervision purposes) to indicate audibly or visibly when certain circuits are closed. Referring to Fig. 48, the coupled switches S, T control lamp circuits L in the ordinary way when A is open. Directly A is closed, closing S or T or both lights the lamps R and applies sufficient p.d. to the bell B to ring it. By using three lamps at R, the bell is protected from injury in the event of failure of the lamp shunting it. If only an indicating pilot lamp is required, the terminals *a*, *b* and the terminals *c*, *d* should be strapped together; the connection *bd*, the switch A and lamps R omitted; and the pilot lamp connected at X, Fig. 48. Closing the switch "piloted" causes the indicating lamp to glow.

Where burglar alarms are used the lighting circuit should be arranged so that some or all lamps (or electric gas lighters) can be lighted from a master switch irrespective of the position of the various room switches. Under the conditions shown in Fig. 49 the lamps LL are "off," but by closing the master switch M, the line AB is made live and the lamps are lighted. Reversing the

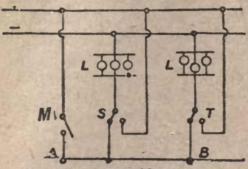


FIG. 49.

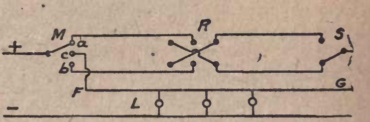


FIG. 50.

setting of ST simply causes the lamps to be supplied directly instead of through the master switch. Fig. 50 shows a master switch M applied to a three-point "on" and "off" control. When the contact arm of M rests on *a* or *b* "on" and "off" control is available at M, R and S, but if M rests on *c* :—(*a*) If *c* be connected to the lead FG, the lamps L are kept "on," irrespective of the setting of R and S. (*b*) If *c* be an "off" contact, the lamps L are kept "off" irrespective of the position of R and S. The switch R may be of the four terminal intermediate type represented in Fig. 38.

SWITCHGEAR AND SWITCHBOARDS.

General Construction.—Desiderata are safety, reliability, simplicity and accessibility to authorised persons. Generally a clear view of the engine-room is required from the switchboard. The arrangement of the latter should be clear and symmetrical. The purpose of all parts should be evident and extension easy and efficient when required. Danger by shock and fire is to be eliminated by suitable interlocking arrangements and by the use where possible of bare conductors, refractory insulating supports, cables enclosed in conduit, insulated by fireproof materials or coated with fire-resisting paint. In the Reyrolle ironclad construction every conductor is enclosed completely in a metal cover, and the busbars, current transformers and other live conductors are immersed in insulating compound so that accidental contact becomes impossible. Breakdowns should be isolated and it should be possible to shut any section down for repair without discontinuing supply. Standard instruments and components should alone be used and automatic switchgear should have loose

handles. For *low and medium pressures* slate or marble panels may be used; the panels should be insulated from the steel frame by bushings and all live conductors should be bushed with mica or equivalent material on boards for pressures exceeding 250 volts (slate) or 500 volts (marble). The surface of slate or marble panels should be polished, enamelled or varnished. White Sicilian marble is best; dove or black is used at times. Slate should be selected free from metallic veins. *For high pressures*, all-steel cubicles may be used with removable panels for front access; moulded stone, brickwork or concrete slabs or reinforced concrete construction may be used with sheet or expanded metal doors. Vertical and horizontal partitions should isolate h.t. switches, current and potential transformers, fuses, etc. Moulded stonework of a particular cell may be grooved to receive dividing slabs of uralite or similar materials; connections from compartment to compartment in each circuit should be by bare conductors on porcelain insulators and through porcelain bushings.

Busbars are generally of high conductivity strip or laminated copper; aluminium offers the advantages of light weight, high ductility and large radiated surface. Temperature rise is generally the limiting factor in switchboard work and for equal temperature rise, aluminium busbars are only 40% as heavy as copper (the comparison being more favourable than in the case of long transmission lines). *Zinc busbars* have been used in Germany during the war; bends must be large and precautions taken against corrosion. If properly isolated, busbars are best left bare; usually they are carried by insulators on wrought-iron brackets. All connections should be bolted on; the effective section should not be reduced by drilling, etc. A double set of busbars for generators and meters with isolating and linking switches makes possible isolation of faulty sections or the running of one generator as a special voltage or frequency and enhances security of supply. In industrial distributing gear and armoured switchgear of the unit type, busbars are completely enclosed and run solid with insulating materials; special end cover allows for cable connections and easy extension by adding a unit at any time.

Connections.—Crossing connections and a confused mass of wiring must be avoided whenever possible; the connections must be kept clear and properly labelled. Connecting charts should show the actual course of wires and cables; it is often well to provide for easy reference a diagrammatic chart showing the nature and function of all connections. Wiring to instruments, etc., may be carried in brass conduits with inspection boxes; wires being distinctively covered to facilitate identification. Fireproof insulations and fireproof paint should be used freely. All connections should be tinned and all sweated con-

nections relieved of mechanical load. Instruments should be placed away from resistances or other sources of heat; a swing bracket frame usually carries synchroscopes and generator voltmeters. Fuses should be placed away from face level; circuit breakers and arresters at top of board.

Automatic and Safety Devices.—Too many *automatic devices* should not be employed, particularly in mines and other situations where maintenance is difficult and conditions bad. In mines thoroughly reliable automatic devices controlling a comparatively small number of sections of the distributing system are preferable to automatic gear on every switch. Relays, etc., should be of the Admiralty type as regards ability to withstand shock and vibration; special enclosure is generally required. Working of automatic devices should be tested periodically in all installations. A time-lag element is very desirable in automatic apparatus exposed to severe temporary variations of load and pressure, etc.; correct selection and gradation of time limits confines shutdown to smallest section of the system. *Fool-proofing* safeguards unskilled labour and protects skilled operators against the results of carelessness or accident. Multiplication of safety devices increases cost, complexity and risk of breakdown; to some extent it engenders carelessness, but the general tendency is to guard against even the rankest folly on the part of operators. Since other lives are frequently involved, this tendency is doubtless justified. Where provided at all, safety gear must be absolutely reliable. Devices may be provided to open circuits on under- or overload or in case of pressure failure or reverse power; various combinations of these features are possible. Trip gear should be low tension operated through transformers in case of a.c. circuits.

Generator and Feeder Regulation.—Close voltage regulation is legally compelled in public supply networks and is in any case essential to secure satisfactory lighting from incandescent filament lamps. In traction and power supply, constant voltage is equally important in that it affects the efficient operation of motors and thus concerns a heavy item of annual expenditure; it is, however, more difficult to secure by ordinary means owing to sudden and violent fluctuations in load. Automatic voltage regulation is alone effective in traction and industrial supply stations. The Tirrill regulator is equally applicable to d.c. or a.c. generators and maintains constant voltage at either the busbars or some remote part of the system according to needs. It can be used also to maintain constant current; to regulate the speed of a motor or motor generator; or to control a reversible booster system. Voltage regulation is effected within $\pm \frac{1}{2}\%$ under any load or power factor within the exciter voltage range for which the regulator is designed. Fig. **51** shows the connections of a Tirrill regulator as used in its simplest form to control

a single shunt generator. Should the voltage fall below normal, the control magnet allows the main contacts to close and, by thus neutralising the effect of the permanently connected coil of the differential relay, allows the relay contacts to close and short circuit the field rheostat. The time constant of the field circuit is kept low so that the generator voltage rises quickly from normal. The control magnet then opens the main contacts and the relay contacts follow; if the voltage again becomes low, the cycle is repeated. Where large generators or machines with laminated poles are concerned, the regulator operates on the exciter field; so also it does when controlling a.c. voltage. The main control magnet is then connected through a potential transformer to the point where it is desired to maintain constant pressure. One main control coil governs any number of relays

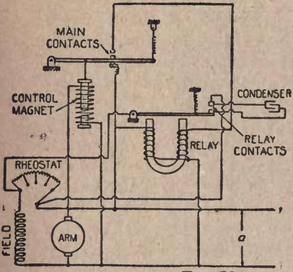


FIG. 51.

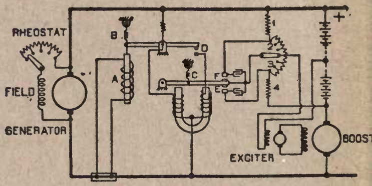


FIG. 52.

(one per exciter). Fig. 52 shows the Tirrill regulator in use with a reversible booster and battery. Increase in load causes the contacts D to open and thus the relay contacts E to close and short circuit 3. On light load, contacts F are closed and 2 is short circuited. Thus the exciter on the booster shaft is excited in one direction or the other and the battery discharges or charges. The limits of charge and discharge are regulated by adjusting the resistances 2, 3. *Feeder Regulation.*—Regulation of individual feeders is required by modern concentration of generating units in stations whence districts offering varying demands are supplied by radiating feeders. Such systems are almost invariably a.c., and for automatic regulation in single or polyphase feeders, variable ratio transformers may be used, the primary being connected across and the secondary in series with the feeder controlled. In one type of induction regulator, the windings are wound on concentric sheet-iron cores one of which (the primary or shunt) can be partially rotated within the other. Regulation

of feeder volts is secured simply by changing the angular position of the cores (by hand or by a servo-motor). Continuous control is provided from a maximum negative to a maximum positive boost (say $\pm$ 5 or 10%); it is easy to maintain certain pressure at a remote point if necessary. According to their capacity (which is but a small percentage of the line capacity) from 92 to 97% efficiency is attainable in induction regulators. For comparatively light loads a switch type regulator may be used operating on the same general principle.

Switches.—Plug switches were used extensively in early central equipment but are now limited to instrument circuits and temporary power connections. It is difficult to ensure good contact, and plug switches should not be used for currents exceeding 150–250 amp. *Knife Switches* are generally employed on l.t. boards. No current should be carried through the hinge. Double break type is recommended with quick spring break on both contacts at once. Back terminals for heavy current; separate fuses for high pressures. Pull to bring out sparking blade should be exerted on it directly and not through the springs, which simply ensure quick break when once started. Arcing tips may be of carbon with or without magnetic blow-out. Alternatively a combined plug and knife switch may be used, the plug opening after the knife and breaking circuits between the apices of copper horns. *Isolating Links* are used on h.t. and some l.t. systems to render circuits dead for cleaning or repair, etc. Porcelain insulators are mounted on an iron or slate (low pressures) base and carry copper contacts and a simple copper switch which must never be used to open or close the circuit under load. *Oil Switches* always break arc at moment current wave passes through zero; this reduces surging. Oil switches are smaller than other switches for given capacity. Oil should not flash below 250° C. Sp. gr. 0·87. Free from acid, alkali and evaporation; submersion of highest live parts in h.t. switches 4 in. or 5 in. *Carbon-tetrachloride or benzinoform* (CCl_4) has been tried as substitute for switch oil. It boils at 76° C., freezes at – 27° C.; sp. gr. 1·6. Disadvantages—high sp. gr.; no lubricating value; rapid evaporation. Corrosion of Cu prevented by tinning where applicable. Glycerine prevents evaporation but forms verdigris on contacts and conducting layer on insulation if these parts be raised for inspection; if level of CCl_4 be lowered flash-over may occur to the "earthed" glycerine. Leads must be taken in at bottom of case and only the operating rod passed through the glycerine. An incombustible substitute for switch oil would be welcome; as a compromise, a 1 : 3 mixture of CCl_4 and oil avoids some of the defects of the former, and in case of fire the CCl_4 distilling first would tend to extinguish flames. Reser-

voirs of CCl_4 near oil switches suggested as fire safeguard. *Contacts* should be carried by porcelain insulators tested to 3 times the working pressure and designed to prevent flash over and creeping. Emergency breaking capacity 10-12 times working load. Moving contacts of wedge or wiping laminated type as case may be; renewable sparking tips. Mechanical or electrical indicators on all switches. All screws and nuts locked. Only one (if either) of two moving metal parts in contact should be of iron otherwise the parts may rust together. *Oil Tanks* are galvanised wrought iron, maple lined. Pressure relief valve and draining valve or other arrangement to carry oil safely away in event of box breaking. *Field Switches.*—No highly inductive circuit such as field, solenoid or brake magnet winding should be broken abruptly. An auxiliary contact should shunt the winding by a non-inductive resistance immediately before opening the circuit. *Buffer Resistances* on transformer oil switches prevent current and pressure surges in opening and closing circuit.

Lightning Arresters.—Horn type is very common; horns may be of galvanised iron $\frac{3}{8}$ in. in diameter. Earth plates should be distinct and as far apart as possible to reduce short circuit currents flowing temporarily when two or more arresters operate simultaneously. A neat combined tension limiter and arrester comprises two brass horn arresters (one shunted by high non-inductive resistance) with zinc rollers at adjacent angles of horns. *Tension Limiters.*—To prevent dangerous static pressure on overhead lines or cables, the conductors are connected to earth through a number of short gaps (say $\frac{1}{32}$ in. between parallel cylinders of brass or other non-arcing metal) and a non-inductive resistance in series. About 500 volts is allowed per gap. Box enclosure prevents accident and access of dust.

Switchboard Construction and Equipment.—Gridiron boards with two sets of busbars at right angles for generators and feeders respectively and with plug-through connections (one grid for each pole) are simple, compact, fireproof and cheap, but liable to bad plug contact and not suitable for high pressure. Modern boards comprise knife or oil switches assembled with the necessary instruments, operating handles or rods, fuses, etc., on insulating panels or in chambers from which rods or leads are carried to control panels. D.C. boards are generally single-storey structures, but more complex than a.c. boards; balancing three-wire circuits and operating storage cells involve complexities; general and traction supply circuits are usually distinct. Arrangement must be made to reverse the polarity of conduit traction systems at intervals. Generation in modern central stations is usually at 3000-11,000 volts, three-phase a.c. current being transformed to lower pressure and converted to d.c. for station or local needs;

industrial consumers and some substations are supplied at the generator pressure, but the latter is transformed up for long distance transmission. Switchboards in such stations are of at least two storeys. In the basement are generator cable races, l.t. busbars and transformers; above them are oil switches, the operating gallery, h.t. busbars, lightning arresters and overhead transmission line connections. Direct mechanical operation of the switchgear is positive and simplest but solenoid or servo-motor control is best for distant control (particularly over tortuous routes). All long control rods should be in tension; free handles should be provided where necessary. H.T. switchgear occupies considerable space, and remote control by handles or master switches on vertical, inclined or horizontal panels makes possible easy control of the largest plant from a small, conveniently situated platform. Pilot lamps indicate the setting of the gear; the latter is inaccessible while live; no h.t. circuit should be brought to the control panel. Automatic oil switches are preferable to fuses for high power h.t. circuits.

Typical Switchboard Equipments.—Low Tension D.C. Boards—enamelled slate base; angle-iron frame; strip-back connections. *Generator Panels*—maximum and reverse current automatic time-lag circuit breaker at top of board. Ammeter and paralleling switch; shunt field regulator, switch and discharge resistance. Quick-break knife switches. Indicating or recording wattmeter. Open scale illuminated voltmeters above board or on end-bracket; plug-in voltmeter across circuit breaker permits exact pressure regulation before paralleling one machine with another. *Feeder Panels.*—Maximum automatic time-lag circuit breaker with free handle and ammeter and knife switch in other line (alternatively quick break knife switches, fuses and ammeter). Indicating or recording wattmeter circuit breakers (not fuses) should be used in traction feeders; lightning arrester and choke coil should be added. *Battery Panels.*—Fig. 53 shows battery panel connections and equipment recommended by the Tudor firm for small installations employing end cells; when the generator supplies the external circuit directly in parallel with the latter, it is connected to the busbars through the change-over switch; no battery charge must then be given. Fig. 54 shows end cells eliminated by use of a reversible booster. The equipment represented is suitable for a large battery supplying a short peak load; end cells are preferable where the battery is to act as emergency standby or supply light load demands. If the booster motor fuse blows the special circuit breaker B opens the booster and prevents the booster set from racing. Both Figs. 53 and 54 are applicable to substations or private plant; the generator connections being then omitted.

Low Tension A.C. Boards.—General construction as above. *Generator Panels.*—Three-phase automatic oil switch with time-lag overload trip coils and reverse power relays. Two current transformers and ammeters; synchroscope and voltmeter socket. Add isolating links and pressure transformers for medium or h.t. boards. *Feeder Panels.*—Three-phase automatic oil switch with overload release; ammeter; add instrument transformers and isolating links for medium and h.t. boards. *High Tension Boards* almost invariably for three-phase a.c.; equipment comprises oil-break switches with or without no-volt overload releases and time-limit devices; totally enclosed in masonry, lattice or

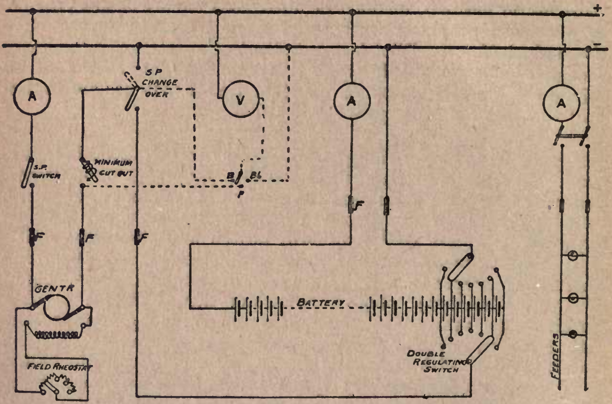


FIG. 53.

cast-iron cells with interlocking doors. Characterised by isolation of circuits and phases; minimum amount of h.t. switchgear used; instruments, pilots and releases, etc., operated by l.t. current; e.h.t. gear is of very special construction and equipment depends on exact circumstances of each case. In e.h.t. circuits, electrostatic capacity of apparatus (especially transformers) may cause severe pressure surges. Inductance is the predominant factor at low pressures; no internal oscillations set up and external ones only impose extra stress on end turns, which may be reinforced or protected by "shock coils." Electrostatic energy increases with $(\text{volts})^3$; very important above, say, 6000 v.; safer then without shock coils. Opening connection between two e.h.t. circuits of different characteristics (*e. g.* transformer

and transmission line) may cause high frequency, pressure surges. Place interrupters on l.t. side of transformers and connect h.t. side to line through isolating switches (never used to break current). Switches between two sections of line are all right so long as transformers near the switches are protected. *Total Output Panels* for all types of boards include recording ampère, volt and watt-hour meters and possibly leakage and p.f. meters, etc.

Industrial Switchgear.—Though rather more expensive than other forms of switchgear, that enclosed by iron casing with dust and moisture proof joints and glands is by far the safest and most

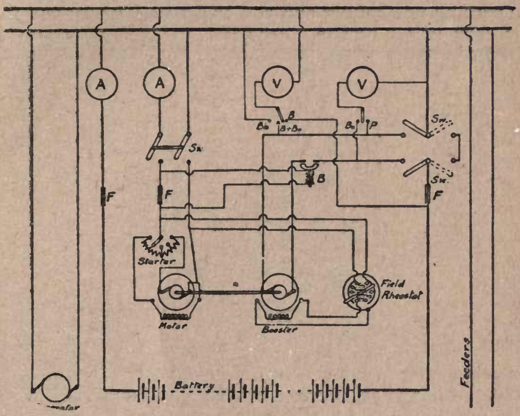


FIG. 54.

reliable for industrial use. Enclosure, coupled with liberal electrical and mechanical design, reduces interruptions of service and maintenance costs to a minimum, so that totally enclosed gear generally proves the cheapest in the long run. Iron cases should be lined with insulating materials and designed so that mechanical shock is not transmitted from case to gear. Ample clearances and breaking capacity are important. Earthing screws should be provided on the case. Vitreous porcelain blocks and pressed micanite sleeves and washers form suitable insulation. Switch jaws and contacts, etc., are frequently mounted rigidly on steel bars which are insulated by mica. The latter is of high insulating value and withstands any climate. Use incombustible insulating fillets between poles or phases and bushed, tapped or

gland inlets. Oil switches should be used in high or extra high pressure circuits and in heavy power circuits. The oil tank should be kept filled with clean dry oil of flash point 300° F. Fig. 55 illustrates a compact and inexpensive ironclad panel (B.T.H.) controlling fully and with certainty individual small motor and generator circuits. A wrought-iron panel carries double pole ironclad lever switch; two main cartridge fuses; ammeter and voltmeter and voltmeter fuse. In some cases a voltmeter is not required; in others a recording wattmeter may be considered desirable. Panels of this construction are suitable for currents up to 100 amp. at 500 volts. *A crane control panel* may carry on a slate base a d.p. circuit breaker (10–300 amp.) with no volt release and 2, 3 or 4 time-lag overload relays, one in each motor circuit. Ammeter and voltmeter and interlock between main switch and motor controllers may be added.

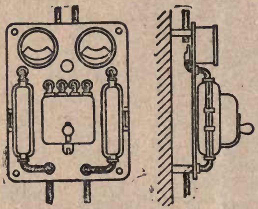


FIG. 55.

The a.c. equipment for this service is similar but uses a 3-pole automatic oil switch instead of the d.c. circuit breaker. In totally enclosed oil-immersed three-phase *star-delta starters* (switch or drum type) devices are usually included to ensure movement from "off" to "star" and then a pause before proceeding to "delta." No-volt and overload release can be incorporated, the latter acting in two phases. Available from 20 to 360 H.P. Similar series-parallel starters for two-phase machines are available up to 80 or 100 H.P., 650 volts. Enclosed auto-starters of the double-throw switch type and provided with several transformer tappings are available up to 200 H.P., 700 volts or 600 H.P., 3300 volts, oil-immersed. Useful *control cabinets* for industrial use comprise switches (automatic or otherwise); ammeter and voltmeter; and ironclad casing with cable sealing boxes. *Barrel or drum controllers* are very convenient for heavy motor control; the barrel may be vertical or horizontal. The most familiar application of this type is on tramcars and electric locos (usually merely a master controller

in the latter case); it is also used in crane cabs, coal-cutters, printing-presses, machine tools and other industrial applications. In its most perfected form the controller embodies all the apparatus required to start, regulate and protect the motor against overload and interruption of supply. For instance, the Vickers pillar, as built for 5–150 H.P., 115–460 volts, contains d.p. overload and no-volt circuit breaker, drum starter, shunt regulator for variable speed motors; resistances for starter and shunt regulator; d.p. fuses—all in weatherproof case and operated by one handle. A starting resistance with 1 min. rating is mounted in the same casing. The hard-drawn copper contacts are renewable; the fingers are carried by laminated steel springs and connected to terminals by flexible copper leads. Since the springs carry negligible current they retain their elasticity indefinitely. Arcing tips are easily renewable. A blow-out coil covering each set and the isolation of each sparking point by its own fireproof chamber are essential features. An interlocked reversing barrel may be incorporated. Units of *pillar type switchgear* can be used as units or any number can be assembled to form a board. Indicating and recording instruments, automatic overload, no-volt and leakage releases can be fitted as desired. The whole can be made flame and explosion proof and interlocked so that access to live parts is impossible. A typical motor control pillar comprises inching or standard starter; field regulator; d.p. knife switches and tubular replacement fuses or double break contactors with no-volt and overload release; ammeter and voltmeter; the whole in a sheet-iron casing with inspection windows on angle-iron framework with cast-iron base *or* in heavy cast-iron casing. For high tension work, isolating links and interlocked door are essential; an automatic oil switch is usual with current and pressure transformers for meters and trip coils.

Mining Switchgear must be enclosed completely by a cast-iron case strong enough to withstand very rough treatment and able to resist internal gas explosion. Casing joints must be wide and tight; switchgear and doors must be interlocked so that parts can only be live when totally enclosed. Open sparking must be impossible; oil-break switches and fuses are valuable in this connection. Insulation must be protected and adequate even when covered with moist coal dust. Remote control and automatic attachments can be arranged; trip coils should operate in case of insulation failure. *Switchboards for underground use* should be of the totally enclosed draw-out type with busbars in cast-iron casings and switches in chambers running out along bracket arms: each switch is isolated completely when drawn out. Any equipment can be built up by assembling units end to end.

FUSES.

Constructional Notes. — All fuses should be protected individually against flash-over and splashing fused metal: enclosed fuses recommended. Bases incombustible, non-conducting, moisture proof. Must be impossible for arc to be maintained between terminals after the fuse blows. Fuses may not be placed in wall plugs, sockets, ceiling roses or lampholders. Branch fuses must be grouped accessibly; arranged symmetrically and labelled. Fuses should be selected and graded so that a fault in a sub-circuit blows the sub-circuit fuse before the main fuse; this is favoured by using copper main fuses and tin or lead branch fuses.

Open strip fuses.—Use only up to 250 v. and under skilled supervision. Guard against molten metal and flash-over. *Semi-enclosed grip fuses* may be used as isolating switches in medium sized installations. *Tubular fuses* may be used up to 600 kw., 750 v., or in special patterns for h.t. circuits. Liberal contact area essential in terminals; preferably clamp by bolting. May be adapted for use as isolating switch. A fine wire shunt acts as throttling resistance. *High tension fuses.*—The important point is to prevent maintenance of the arc, by cooling and removing metallic vapour. Switch-fuses should have horn tips. Limiting power per fuse is about 300 kws. in air and 3000 kws. in oil. Permanent oil-immersion not satisfactory. Safer and more effective to submerge one terminal automatically when the fuse blows. Out-of-doors switch-fuses are convenient in overhead service lines and should be provided with horns to break the arc. *Magnetic blow-out coils* may be fitted to heavy current d.c. fuses in conjunction with horn gaps, to serve the double purpose of breaking the arc promptly and throttling current directly the fuse blows.

Rating.—The I.E.E. wiring rules state that fuses must not overheat when full current flows continuously. When working current is not greater than 10 amps., the fuse must operate at not more than three times working current; above 10 amps. the fusing limit is twice working current. Good rating practice for fuses is:—House circuits 75% overload; main lighting circuits 40%; motor circuits 50%. There is a certain time lag in bringing the fuse to melting-point. Oxidation reduces current carrying capacity and causes premature blowing. I.E.E. rule is that no fuse of less than 3 amps. (fusing at 9 amps.) need be inserted in final sub-circuits. Where fuse wire would be larger than 13 S.W.G., it is better to use strip fuses or paralleled strands of smaller wire. A number of fine wires woven into an asbestos strip is a good arrangement. Silver wires are immune from

,xidation, but below 5 amps. capacity the wire is too small for mechanical safety, and higher resistance metal should be used.

Preece's law for fusing current is $I = ad^{\frac{3}{2}}$; where I = fusing amps.; a = numerical factor = 10,244 for copper; 7,585 for aluminium; 1,642 for tin; 1,379 for lead; when the diameter d of wire is in inches. The table gives fusing currents for various sizes of various wires, assuming that fuses are long enough for the cooling action of terminals to be neglected.

FUSING CURRENT IN AMPÈRES

Size of Wire S.W.G.	Diameter in Inches.	Copper.	Alu-minium.	Lead.	Tin.	Lead 2; Tin 1.
40	0·0048	3·41	2·52	0·46	0·55	0·44
36	0·0076	6·79	5·03	0·92	1·09	0·87
32	0·0108	11·5	8·5	1·55	1·84	1·48
30	0·0124	14·1	10·4	1·9	2·27	1·82
28	0·0148	18·4	13·6	2·48	2·96	2·37
26	0·018	24·7	18·3	3·33	3·96	3·18
24	0·022	33·4	24·7	4·5	5·36	4·3
22	0·028	48	35·5	6·46	7·69	6·17
20	0·036	69·9	51·7	9·41	11·2	9
19	0·040	81·5	60·3	10·9	13	10·4
18	0·048	107	79·7	14·5	17·2	13·8
17	0·056	132	98	17·8	21·2	17
16	0·064	166	122	22·3	26·6	21·3
15	0·072	198	146	26·6	31·7	25·4
14	0·080	232	171	31·2	37·1	29·8
13	0·092	286	212	38·5	46	37·8

A formula given by Roth for silver fuses is $I = \sqrt{[2300d^{2\cdot34} + (60{,}000\ d^4/l^{1\cdot35})]}$; where I = fusing amps.; d = diam. of wire (*millimetres*); l = free length of fuse (*centimetres*).

A heat insulating tube round a fuse reduces the rating to about 92% of the "open" fusing current in the case of a single wire; 84% for 2 wires in parallel; and 78% for 3 wires.

FUSING-POINTS OF METALS.

	Deg. F.		Deg. F.
Aluminium	1240	Lead	625
Antimony	803	Manganese	3000
Bismuth	509	Nickel	2570
Brass (Cast)	1650	Platinum	4710
Copper (Cast)	2000	Silver	1830
Gold	2160	Steel	2570
Gun-Metal	1900	Tantalum	4160
Iron (Cast)	2000	Tin	463
Iron (Wrought)	2880	Zinc	780

ELECTRICAL MEASUREMENTS AND TESTING.

This title covers so wide a field that any treatment short of that possible in a voluminous text-book must necessarily be incomplete. In order that a maximum of information may be given in minimum space, notes on various tests are given without explanations of theory and without attempting to lead up from one test to another. The tests are, however, classified in several broad groups for convenience in reference. Attention may be directed to the chapters on Scope and Errors of Electrical Measuring Instruments and on Electricity Meters.

Range of Instruments.—If an ammeter of resistance r reads i amps. per scale division, it will read 1 volt per scale division when used in series with a resistance $R = (1 - ir)/i$ ohms. To increase range of voltmeter n times, use in series with it a resistance $= (n - 1)$ times the voltmeter resistance. Range of electrostatic voltmeter cannot be increased by series resistance, nor can such an instrument be used in series with any current-carrying instrument to increase the range of either. The range of two current voltmeters in series is not necessarily the sum of their top scale readings; it depends on the relative resistances of the instruments which determines the distribution of pressure between them.

Shunts.—In order to pass $(1/n)$ of the main current through a galvanometer (or other apparatus) of resistance r, the shunt resistance, $s = r/(n - 1)$. The "multiplying power" of the shunt $= (r + s)/s$. Use of a shunt reduces the effective resistance of the circuit and may or may not reduce the galvanometer current, according to the resistance of the rest of the circuit. If the "external" resistance be low, shunting a galvanometer produces little or no effect on its deflection. If the "external" resistance be high, the current through the galvanometer is reduced nearly in the ratio $s/(s + r)$. It is difficult to construct simple shunts accurate enough (in point of resistance) to give accurately, a specified high multiplying power; also, differences in temperature cause variations in shunt ratio even if shunt and galvanometer windings be of same metal. A *universal shunt* will give exact multiplication factors whatever the resistance of the galvanometer with which it is used; it is desirable that the latter be low compared with that of the whole shunt. The galvanometer is connected across the whole shunt, which may consist of n equal sections totalling r ohms resistance. Then if the main current be passed through only $\frac{1}{n}$th of the shunt, the

multiplying power of the latter is n. If the main current be passed through t of the n equal sections of the shunt, the multiplying factor $= (n/t)$.

Potentiometer Tests.—Forms of potentiometer and tests possible are too numerous for complete treatment here. The principle employed is that the fall of potential along a suitable resistance carrying steady current is balanced (by aid of a galvanometer on the null principle) against the p.d. to be measured. The resistance is calibrated directly to read in volts, and in order that this calibration may be correct a standard cell is connected to oppose the p.d. on the appropriate potentiometer resistance (as indicated by the calibration), and the main current is then varied till balance is obtained. The main current being then kept constant (checked by frequent reference to standard cell) unknown pressures up to 1·5 v. or so can be determined by opposing them to the drop in the slide wire and obtaining a balance. The p.d. thus measured may be: (1) the e.m.f. of a primary cell; (2) a known fraction of a high pressure, divided by a volt box and applicable to voltmeter calibration; (3) p.d. across a low resistance, indicating value of latter if current through it is known (resistance measurement), or current through it if resistance is known (current measurement or ammeter calibration). In commercial potentiometers the main resistance generally consists of 14 coils of equal resistance (to which tapping-connection is made by a dial switch) and a slide wire, of the same resistance in which the fine adjustment is made. Measurements to within 0·0001 volt are made easily in commercial potentiometers.

Current and Pressure Measurements.—There are many convenient *portable testing sets* on the market, and for details of these reference should be made to makers' catalogues. The principle on which *pressure and current measurements* are made may be thus explained, by reference to Fig. 56 (1, 2). In (1) a millivoltmeter is connected across part of a high resistance R (say 100,000 ohms); the latter is connected across the mains, and the division points a, b, etc., are chosen so that on a, one scale division of V corresponds to 0·01 volts; on b, one division corresponds to 0·1 volt and so on. The portion of R used naturally depends on the pressure to be measured. For current measurements, a second millivoltmeter (calibrated in amperes) is connected across one of several shunts S_1, S_2, S_3, etc. (2). The whole main current is passed through this shunt and the value of the latter is chosen so that 1 division on A corresponds to 0·01 amp,or 0·1 or 1·0 amp., etc. Only those leads used in calibrating A (or others of equal resistance) may be used.

The Tangent Galvanometer is set with its coils parallel to the earth's field; a field at right angles to this is produced by the

coils and if the deflection be θ, the current $= \mathrm{H}(\tan\theta)/\mathrm{G}$, where H is the horizontal component of the earth's field and G is the galvanometer "constant," determined once for all. For any one place H is practically constant, so that $\mathrm{H}/\mathrm{G} =$ a constant "reduction factor" and $\mathrm{C} = \mathrm{K}\tan\theta$. If the coils be turned through an angle α till the magnet again lies in their plane (*i. e.* deflection of pointer $= 0$), C is then proportional to $\sin\alpha$.

Measuring Quantity of Electricity by ballistic galvanometer: Observe first swing of needle (say $\theta°$), then Quantity $= \mathrm{Q}\sin(\theta/2)$, where Q is the "ballistic constant" of the instrument. This method is only applicable to measuring quantity of electricity from condenser discharge, or due to search coil movements, etc., the fundamental assumption being that the discharge is completed before the needle moves from rest. To allow for "damping" effect of air friction, etc. :—Quantity $= \mathrm{Q}(1 + \lambda/2)$

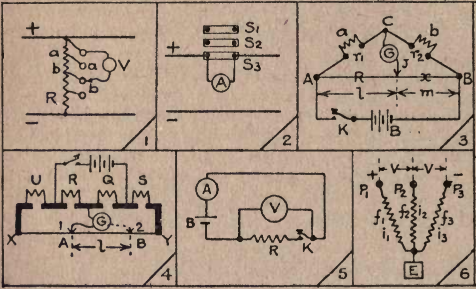


FIG. 56.

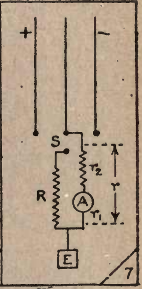


FIG. 57.

$\sin(\theta/2)$ where $\lambda =$ logarithmic decrement $= (1/n).\log.(\mathrm{D}/d)$; D, d being the first and last deflections of a series of n swings. To determine Q, discharge a known quantity of electricity through the galvanometer from a condenser of capacity K charged to pressure V. [Quantity $= \mathrm{KV} = \mathrm{Q}(1 + \lambda/2).\sin(\theta/2)$.] Alternatively, a "magnetic standard" may be used, the known quantity of current being then (Turns $\times$ Flux/Resistance $\times 10^8$) coulombs.

Resistance Measurements.—There is an almost infinite number of ways and means of measuring electrical resistance, indeed, at least one large text-book has been devoted entirely to this subject. *Substitution Method.*—Substitute known (R) for unknown (r) resistance in circuit containing constant voltage battery and galvanometer till deflection is same in each case; then $r = \mathrm{R}$. *Voltmeter and Ammeter Method.*—Where we have to deal with D.C. only, it is often possible to use an ammeter to

measure the current I flowing through the resistance R (whose value is required) and a voltmeter to measure the p.d. V across the resistance; then by Ohm's Law, $R = (V/I)$ ohms. It is important that the voltmeter resistance be high, otherwise the current actually flowing through the unknown resistance is appreciably less than I (by the amount of the current flowing through the volt-meter) and the above simple formula is no longer true. Whether it is more accurate to measure the p.d. across (resistance and ammeter) or to measure current through (resistance and voltmeter), *i. e.* to connect voltmeter in long or short shunt, depends on the resistances of the instrument and is easily decided for each particular case. In many cases a sufficiently steady current for the preceding test may be obtained conveniently by connecting the resistance to be measured in series with an ammeter, between fuse terminals (in one conductor of a lighting circuit) from which the fuse is removed; and then switching on glow lamps till a suitable current is obtained. A sufficiently accurate test for joint resistance in heavy cables, tramrails, etc., is to measure pressure drop across it when passing known heavy current; a millivoltmeter is required. Special direct reading joint testing sets are on the market.

In its simplest form, the *Wheatstone bridge* consists of a slide wire AB (Fig. 56 (3)) of uniform section and resistance in parallel with two resistances a, b in series; a galvanometer G with sliding contact J, and a battery B and key K, being connected as shown. When G shows no deflection (*i. e.* zero p.d. between C and J) :—$a : b = l : m$, hence if b be a known resistance, we have that the "unknown" resistance $a = b \times l/m$. Generally the galvanometer resistance is higher than that of the battery, and it is then best to connect it between the junction of the two higher and the junction of the two lower resistances of the bridge. For maximum accuracy, it is best to work with equal ratio arms. *In other forms* of the bridge a, b and l may be resistance coils of known value and the unknown resistance x connected between J and B (*i. e.* in place of m, Fig. 56 (3)), then $x = Rr_2/r_1$. The variable resistances r_1, r_2 and R may be put in or out of circuit by a dial switch or by a plug board, the values of the resistances being marked alongside the switch or plug contacts. Clearly, if $r_2 = r_1$, the $x = R$ when balance is obtained. To suit other values of x, the "ratio arms" a, b may be chosen in the ratio 1 : 10 or 10 : 1 and so on. In any case, the value of x is obtained practically by inspection; the only mathematical operation involved being shifting the decimal place one way or the other. Accuracy is greatest when all four arms of the "bridge" are as nearly as possible of equal resistance. *Carey-Foster bridge* for determining small differences in resistance between U, S, Fig. 56 (4). The ratio R : Q is kept constant. Balance is obtained at A with connections shown; U, S are then

interchanged and balance obtained at B. Then if r = resistance of XY *per unit length*:—$(U - S) = r.l.$ Either U or S is supposed known accurately. This method is very useful for standardization purposes, measuring tempr. coefficients of resistance, etc.; contact resistance at terminals must be kept constant, preferably by use of *Hg*.

Battery Resistance.—Connect battery to resistance, key and ammeter as in Fig. 56 (5); join voltmeter across key and resistance so that, when key is "off," the voltmeter reads e.m.f. E of battery and when key is down, the voltmeter reads p.d. V across R, the current in circuit being A amps. Then: Internal resistance of battery $= r = (E - V)/A$ ohms. If the value of R be known, it is unnecessary to measure A, for: $r = R (E - V)/V$ ohms. A more accurate expression, allowing for the fact that current is still flowing through the voltmeter when the key is up, is: $r = [(E - V)/(A - a)] - s$; where E and a = volt- and ammeter-readings with key up; V and A = ditto with key down; and s = ammeter resistance. Readings should be taken as quickly as possible, to avoid polarization effects. *Resistance of Electrolyte.*—D.C. cannot be used because of electrolytic decomposition and back e.m.f. of polarization. Resistance of known length and section of electrolyte is measured between two electrodes in a calibrated glass tube dipping into a vessel of electrolyte (so arranged that current has only the one path between the electrodes). A slide-wire Wheatstone bridge is used with induction coil as source of current and telephone instead of galvanometer. The telephone is practically silent when balance is obtained; it is generally best to connect it across the ends of the slide-wire.

Insulation Resistance.—In testing the insulation resistance of house wiring a direct reading ohmeter may be used. (*See* "Electrical Measuring Instruments.") Make tests (1) between conductors, all lamps, heaters, motors, etc., being first removed and all switches closed. (2) Between the conductors and earth, all lamps, etc., being now in place, switches open, and ohmeter connected between any convenient point in the circuit and "earth" (as represented by a water pipe or lightning conductor). Abnormally high resistance probably indicates defective earth connection or omission of fuses in circuit tested. Under the new I.E.E. rules, insulation resistance of circuits between conductors and between conductors and earth must be at least 30 megohms ÷ No. of "points" in circuit tested. The tests must be made on the installation as a whole and on its individual sub-circuits. The insulation resistance between live parts and frame of motors, heating appliances, arc lamps, etc., must be at least 1 megohm. In lighting circuits, all lamps being connected, switches on and fuses in, the insulation resistance of all

or part of the installation must be at least (25 megohms ÷ No. of lamps). Naturally much higher insulation resistance is required in high pressure cables.

Insulation Resistance of Cables.—If p.d. between conductors of a 2-wire network = V volts; p.d. positive to earth = V_1; p.d. negative to earth = V_2; and voltmeter resistance = r ohms; $V = V_1 + [(V_1/r) + (V_1/R_1)]R_2 = V_2 + [(V_2/a) + (V_2/R_2)]R_1$ where R_1R_2 = insulation resistances of mains to earth. Insulation resistance of 3-*wire network*; without interrupting supply :—Let p.d. on each side of the system be V volts (Fig. 56 (6)); i_1, i_2, i_3 = leakage currents; a, b, c = *reciprocals* of insulation resistances f_1, f_2, f_3 (*i. e.* $a = 1/f_1$, etc.); F = insulation resistance of network $(1/F = a + b + c)$; P_1, P_2, P_3 = absolute potentials of mains above earth, as measured by a voltmeter of resistance G ohms. Then $F = G\ \{[V/(P_1 - P_2)] - 1\}$. *Another Method.* Connect middle wire through milliammeter and high resistance to earth; read deflection; shunt instrument and resistance by another resistance S such that reading of milliammeter is halved. Then $(1/F) = (1/S) - (1/G)$ where F = insulation resistance and G = instrument resistance. If G be large compared with fault resistance, F = S approximately. This method is useful for insulation resistances about 100 ohms. *Another Method.* A centre zero ammeter, A Fig. 57, of resistance r_1, is connected in series with a resistance r_2 (total r ohms) between neutral and earth. A resistance $R = r$ is connected in parallel through the switch S. If d_1 = reading with S open, and d_2 that with S closed, the insulation resistance of the network $= r(d_1 - d_2)/(2d_2 - d_1)$. If r_2 be omitted, R must $= r_1$ and the latter is substituted for r in the equation for insulation resistance.

Tank Measurement of Insulation Resistance of Cable.—Leakage current between core of cable and water in which it is immersed is measured directly by a galvanometer calibrated by aid of standard resistances. A relatively large leakage current flows over the surface of the dielectric from core to water; in order that this may not vitiate the galvanometer reading or damage the delicate instrument, a guard wire is connected from that terminal of the galvanometer not connected to the core to the dielectric at each end of the cable, near the core.

Armature Windings.—An easy and useful means of testing the insulation of dynamo or motor armature windings in works (during manufacture or after repair and before the commutator is in place) is to connect all the coils temporarily in series and apply an A.C. pressure of, say, 100 volts to, say, 10 adjacent coils in a series of 100 coils. The whole series then acts as an autotransformer, and the remaining 90 coils are subjected to a high induced voltage, the magnitude of which is determined

by the ratio of the sections into which the series of coils is divided. By varying the coils to which the supply is applied, all the coils can quickly be subjected to the high pressure test. The precautions usual when working with high voltages must be observed. *Armature Winding and Commutator* may be checked for equality of resistance and correctness of connections by passing continuous current through the armature *via* two wires connected to diametrically opposite points on the commutator. A galvanometer tapped across adjacent commutator bars in turn, should give equal deflection in each case; the current is adjusted to give a convenient deflection. *Insulation Resistance* between windings and between them and frame may be measured by means of a megger or similar instrument. Working pressure ÷ insulation resistance, *i. e.* leakage current, should not exceed 1/5000 amp. in medium pressure or 1/10000 amp. in high pressure machinery. *Breakdown Test* on the insulation of the windings is obtained by applying several thousands volts (from a testing transformer through a fine fuse wire) between winding conductor and frame. D.C. armature insulation from frame may be tested by maintenance of 1500 to 2000 v. (according as working pressure is 200 to 1000 v.) test pressure for one minute and twice this pressure momentarily. The latter test may also be applied to field coils. Insulation from frame of windings in A.C. machines should be tested to twice working voltage. In A.C. tests the transformer used must be able to maintain the desired test pressure whilst supplying the charging current of the apparatus tested; the desirable transformer capacity for various test voltages is:—1 kw. up to 2000 v.; 5 kws. up to 10,000 v.; 30 kws. up to 30,000 v.; and thence proportionately.

Continuity and Fault Location: *Continuity Test.*—Make the conductor or winding whose continuity is to be tested, part of a circuit containing primary battery and bell or galvanometer. Latter is preferable unless working over a distance; unsteady deflection indicates loose contact. Continuity of lead sheathing on wires should be tested by current of several amperes so that weak parts may be detected by burning out. *Fault Location.*—When possible it is best to work on a *loop* of the defective cable; this being a "null" method the actual value of the fault resistance or its variation, does not affect the result. When the cable tested has portions of different sectional areas, it is convenient to reduce the length of each portion to the equivalent length of conductor of the same area as the faulty part. If leads are of appreciable length their resistance must be allowed for. Tempr. corrections should be applied where the tempr. varies along the loop. *Murray Test.*—Referring to Fig. 58 (8), a slide wire is placed across the terminals of the loop; a Wheatstone bridge circuit is thus made and when balance is obtained,

$a : b = c : d$, so that, the "equivalent" length of the loop being l, the fault is (lc/d), *i. e.* (la/b) from A, the exact position being determined by reconverting the "equivalent" length c according to the sectional areas of the cables composing it. *Varley Test* (Fig. 58 (9)).—Resistance r is adjusted till balance obtained. Then $a : b = c : (d + r) = (l - d) : (d + r)$ where l is total length of loop. Knowing the total resistance of the loop and the resistance up to the fault ($d = (bl - ar)/(a + b)$, the position of the fault is determined. For convenience, $a : b$ should be $1 : 10$ or $1 : 100$, etc. A high voltage generator is used for a high resistance fault, and a few cells for a low resistance fault. If the loop resistance be very small, r is so small that accuracy is sacrificed. *Fall of Potential Method.*—A length of sound cable AB is connected in series with the faulty cable BD (see 10) to the end of D of which a pilot or other conductor ND is connected. The galvanometer G is a high resistance instrument. Current is kept constant by variable series resistance K. Connect LM and read deflection d_1; connect MN and read deflection d_2. Then resistance of damaged cable to fault $= X = Rd_2/d_1$. The resistance R of AB is known. The "equivalent" length of BC as thus determined must be increased 0·22% for every 1° F. higher tempr. of AB as compared with BC. The position of an *open circuit* X (Fig. 58 (11)) may be found by connecting a pair of sound wires (similar to the faulty pair), as shown and then varying r_1 r_2 till the telephone T gives minimum sound when A.C. is supplied to the circuit from induction coil M. Then $d = lr_1/r_2$. In some cases it is possible to compare the reading q_1 of a ballistic galvanometer when a charged portion of the faulty line is discharged through it with the deflection q_2 when a known length l of similar but sound cable is discharged. Then: Distance to the break $= lq_1/q_2$. Faults on *A.C. cables* or *overhead lines* can frequently be located by walking over or under the line carrying a large former-wound coil of wire connected in series with a telephone receiver. The position of the coil (in which currents are induced electromagnetically) is kept as constant as possible with regard to the line, and on arriving at the fault the character of the sound heard in the receiver changes or the sound vanishes.

Dynamo and Motor Tests.—The following notes are additional to those given above in connection with insulation tests. *Heating Tests.*—Temperature of windings after delivering full load for 6 hours and then 25% overload for ½ hour may be determined approximately by measuring the resistance of the winding before and after the trial, then $R_1 = R_0(1 + a.t)$ where t = mean tempr. rise in degrees Cent. and $a = 0{\cdot}004$ for copper. Accurate determination of maximum temprs. in deep windings (*e. g.* field coils) is a difficult matter and needs special equipment, including

thermocouples. N.P.L. tests indicate that the maximum tempr. in field coils may be about 20° C. higher than the mean value obtained by the above resistance method. *Characteristic Curves.* By taking simultaneous readings of voltage, current, and speed (the latter being as nearly constant as possible), the load characteristic of a generator is obtained by plotting ($V \times N/N^1$) against current, where V = observed volts and N^1, N = actual and intended (constant) speed respectively. The most useful working characteristic of a motor is the curve between current (*i. e.* load) and speed; in this case constant voltage is assumed, hence the actual speed should be multiplied by Assumed (constant) volts / Actual volts before plotting. *Efficiency Tests.*—To determine the efficiency of a generator at various outputs (thus deriving a complete efficiency curve) involves knowing the input corresponding to each output. If the generator is driven by an engine indicator cards must be taken for a complete trial. If

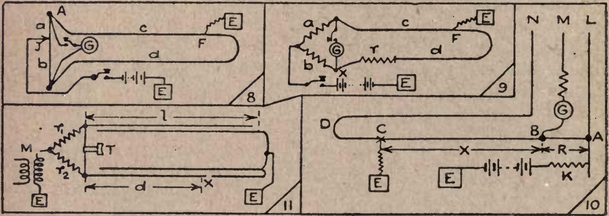


FIG. 58.

the generator is driven by an electric motor, the efficiency curve of which is known, it is only necessary to measure the electrical input to the motor (by volt- and am-meter or by wattmeter), to determine the generator input. When testing motor efficiency, the input is measured electrically and the output either mechanically (by a dynamometer brake) or electrically (through a generator of known efficiency supplying a variable load of lamps or water rheostat, etc.). The *Hopkinson Test* for two similar motors (or dynamos) consists in coupling the machines both mechanically and electrically, so that one acts as a motor and drives the other as a dynamo from which, in turn, it receives the major portion of the electrical energy required to drive it. The balance of energy required to keep the pair of machines running steadily at the load in question, is supplied from an external source of current supply, is measured by wattmeter or otherwise, and obviously equals twice the loss in either of the two similar machines at the load concerned. The great advantage of this method is that two machines, each of, say, 1000 kws. capacity, can be tested

at full load by the expenditure of, say, 100 kws., assuming the full load efficiency of each machine to be 95%. The test is best adapted for use in the maker's works. For all commercial purposes the performance curves issued by reputable manufacturers of dynamos and motors can be relied upon as accurate; special test curves for individual machines are obtainable gratis or at small cost from the makers. *Alternator Characteristics.*—Curves of open-circuit pressure and short-circuit amperes are first required. The alternator being driven at constant (normal) speed, the terminal e.m.f. is plotted against various values of field current. Then the armature is short-circuited and values of short-circuit current are obtained, corresponding to various field currents. Then for each field current, the impedance of the machine = open-circuit e.m.f./short-circuit current = $\sqrt{(R^2 + 4\pi^2 f^2 L^2)}$, where R = resistance of windings and can be measured; f = frequency; and L = inductance, and can be calculated from the above equation.

A.C. Measurements : *Impedance.*—To measure the impedance of, say, a choking coil of inductance L and resistance R, a non-inductive resistance r is connected in series, and simultaneous readings are taken of the p.d. across r, across the choker, and across both in series. This may be done by three voltmeters or by a single instrument, using two 2-way switches and substitutional resistances to take the place of the two voltmeters suppressed. Calling the three readings V_1, V_2, V_3, construct a triangle showing these to scale, then the angle *outside* the triangle between V_2 and V_1 produced is the angle of log. θ of the choker. The power factor of the choker is tan θ and its impedance is V_2/I, where I = current flowing = V_1/r. *A.C. Power.*—The question of A.C. power measurement is complicated by an indefinite multiplication of effects due to phase displacement, inductance and capacity errors in measuring instruments and so on. Complete treatment of these matters is impossible in these pages. The following methods will be found useful for practical purposes. When wattmeters are used care must be taken: (*a*) That the instruments are compensated for such errors as would otherwise be serious under the conditions of the test; (*b*) That the instruments are properly connected; (*c*) That their readings are properly compounded to give the aggregate power in polyphase circuits. *Three Voltmeter Method.*—Connections being as in Fig. **59**, Power = $C(V^2 - V_1{}^2 - V_2{}^2)/2V_2$ watts. Knowing the value of the non-inductive resistance R (Fig. **59**), it is possible to dispense with the ammeter, for then Power = $(V^2 - V_1{}^2 - V_2{}^2)/2R$. The apparatus required may be reduced further and only one calibration error left, by connecting one voltmeter and two 2-way switches as in Fig. **60**. When the switches are on contacts 0, 0 the reading is V; on 1, 1 the reading is V_1;

and 2, 2 the reading is V_2. The above formulæ still apply. *Three Ammeter Method.*—This method is better than the former for loads of low power factor and does not necessitate the use of pressure higher than the normal for the measurement. Using three ammeters and one voltmeter connected as in Fig. 61, the non-inductive resistance being in shunt with the A.C. load, Power $= \frac{1}{2}V(C_1^2 - C_2^2 - C_3^2)/C_3$, or, knowing the value of R, Power $= \frac{1}{2}R(C_1^2 - C_2^2 - C_3^2)$ watts. A single instrument (involving a single calibration error) can be used by arranging connections as in Fig. 62. The arms of switch II are coupled mechanically but not electrically, and on tracing connections it will be seen that A reads C_1, C_2, C_3 in turn. *Two Wattmeter Method.*—Referring to Fig. 63, V_1, V_2, V_3 = instantaneous phase p.d.'s; and C_1, C_2, C_3 represent instantaneous phase currents. The instantaneous power, therefore, equals $(V_1C_1 + V_2C_2 + V_3C_3)$.

FIG. 59.

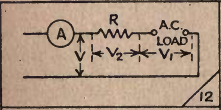
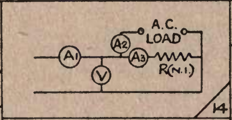


FIG. 61.



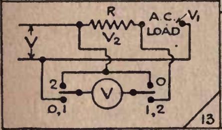


FIG. 60.

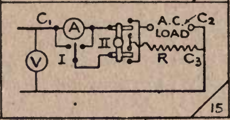


FIG. 62.

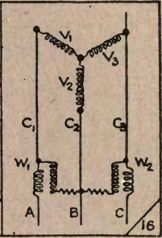


FIG. 63.

Now $(C_1 + C_2 + C_3) = 0$ since the algebraic sum of three-phase currents is always zero. Hence, Power $= (V_1 - V_2)C_1 + (V_3 - V_2)C_3 = (W_1 + W_2)$, where W_1, W_2 are the readings of two wattmeters connected as shown. This result makes no assumptions regarding the state of balance of the load or the directions of current flow at the moment. When measuring inductive loads, one wattmeter may show a negative reading; the shunt connections of that instrument must then be reversed and the arithmetical difference taken instead of the sum of the two readings; this still amounts to taking the algebraic sum of the original two readings. *Power Factor.*—The principle employed in commercial power factor or phase meters is that two sets of windings (one excited by pressure the other by current), set themselves in a relative position varying with the phase difference between the fields produced by the currents flowing in them. One set of coils is movable under spring control and carries a pointer indicating the power factor on a calibrated scale.

There are various types of electrostatic instruments available for direct indication of *A.C. pressures* in laboratory or on switchboard. An instrument of the quadrant electrometer type may be used for high sensitivity measurements. A delicately suspended needle or vane lies within four hollow quadrants; the whole is first earthed whilst the mechanical zero of the needle is taken; this will not be altered when the needle is charged (the quadrants remaining earthed), so long as the needle floats centrally. On establishing a p.d. $= v$ between the pairs of quadrants, and a p.d. V between the needle and one pair of quadrants, the deflection α V, v and if V be fixed and high, the deflection α v and with a high degree of sensitivity. *Wave Tracing.*—Using a D.C. charging pressure and tapping-off one point at a time from an A.C. wave the electrometer will give a series of readings enabling the complete wave to be drawn. The use

FIG 65. FIG. 67.

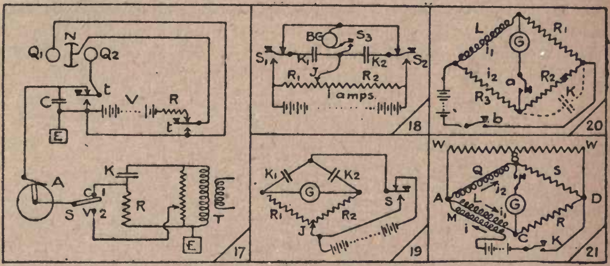


FIG. 64. FIG. 66 FIG. 68.

of an oscillograph is generally to be preferred in practice. *Testing Condenser Dielectric.*—In Fig. 64, the condenser K, whose dielectric loss is to be determined, is charged through a non-inductive resistance by a step-up transformer T, and the curves of pressure applied to it and current flowing through it are traced by aid of the synchronous contact maker A and the electrometer shown diagrammatically at NQ. Connections being as shown, it will be seen that the deflection of the needle N varies with the current flowing through K, when S is on contact 1; and with pressure across K, when S is on 2. By varying the angular setting of the brush bearing on A, the complete pressure and current wave for K can be quickly determined and the power derived thence. The area under the current curve up to various time ordinates (*i. e.* $\int C.dt$) is plotted against the corresponding value of voltage V; a loop of dielectric hysteresis is obtained and the area within this is proportional to the energy loss in the dielectric. The quadrant Q_1 is earthed permanently; N and Q_2

are earthed by pressing the keys t. The needle is charged by the battery V which is in series with a high resistance R to protect it against short circuit between N and Q.

The Capacity of a Condenser may be measured in terms of that of another (assumed known) by charging each condenser in turn to the same pressure and discharging through a ballistic galvanometer to obtain deflections d_1, d_2, then $K_1 = K_2.d_1/d_2$. Connections for Kelvin's "*mixture*" *method* are shown Fig. 65. Pressing keys S_1, S_2 causes condensers K_1, K_2 to be charged to pressures iR_1, iR_2. On releasing S_1, S_2 these charges "mix" and by pressing S_3 (after say 10 seconds) we obtain no kick on the ballistic galvanometer G *if* J is on the balance point. When balance is obtained, $K_1 : K_2 = R_2 : R_1$. For best results a very high voltage battery is required, and the resistance R must also be very high. *Bridge Method.*—Pressing the key S (Fig. 66) short circuits the bridge, releasing it causes the condensers K_1, K_2 to be charged. The contact J is shifted till no deflection is obtained then $K_1 : K_2 = R_2 : R_1$; it should be noted that this is the inverse of the ordinary Wheatstone bridge law Fig. 56 (3). The key S should be manipulated slowly.

Self-Induction.—In the Rayleigh bridge (Fig. 67) a balance is first obtained for resistance (R_1, R_2, R_3 being non-inductive and L being the inductance under investigation). On opening the key b, keeping a closed, the collapse of the field in L induces a current which causes a deflection d_1 on G. A small resistance r is then inserted in series with L, to upset the resistance balance of the bridge, and the steady deflection d_2, obtained when a and b are pressed, is noted. Then if T be the periodic time of the needle, and λ the logarithmic decrement of the galvanometer, the inductance of $L = (rT/\pi)[(1 + \lambda/2)\sin(d_1/2)]/\tan d_2$. In a modification of this method, the procedure is: (1) Balance for resistance, current being steady. (2) Observe swing S_1 on opening key b. (3) *Instead* of adding resistance to L (as above), we *now* shunt the resistance arm R_2 by a known capacity K (see dotted lines in (20)) and observe swing S_2 on opening or closing battery circuit. Then $L = KR_2pS_1/(S_1 - S_2)$ henries, where p = resistance of L. *Mutual Induction.*—The method illustrated in Fig. 68 for obtaining the mutual inductance of M, L consists in arranging the coils so that mutual inductance opposes the effect of the self-inductance of L. The ratio arms are varied till no galvanometer throw is obtained on making and breaking the battery circuit. Then $L = -M(1 + P/Q) = -M(1 + R/S)$. The difficulty is to obtain balance, hence it is best to balance the bridge for resistance and then apply a shunt resistance W, by varying which we can obtain a balance, so that G does not deflect on opening or closing K. Then $L = -M[1 + (P + R)/W + P/Q]$.

ELECTRICITY METERS.

Electricity meters may be classified as follows :—

I.—D.C. Types	—Electrolytic.		
	Magneto-motor	—unbraked.	
		braked.	
		unipolar mercury.	
II.—D.C.; A.C. Types	—Dynamo-motor	—Thomson.	
	Aron clock meters.		
III.—A.C. Types	—Induction meters.		

I.—D.C. Types.—*Electrolytic* meters depend on the fact that the weight of electrolytic products, liberated as gas or deposited as metal, by the passage of current through an electrolyte, varies with the (ampère-hours), *i. e.*, with the *quantity* of electricity flowing. In the *Bastian* meter, nickel electrodes are immersed in a 10% caustic soda solution which is covered with paraffin to prevent evaporation. The fall in level of the liquid, as read on a scale behind the vertical container, forms a measure of the quantity of electricity which has traversed the meter. Filling the meter is troublesome, and 2–3 v. internal pressure drop occurs. In a portable type of this meter, a special cap with valve is fitted over the top of the tube, so that the meter can be carried about without fear of spilling, and connected in various electric heating and cooking circuits—thus gaining for the consumer the advantage of reduced heating tariff without involving the expense of separate wiring. In the *Wright-shunted electrolytic* meter (Fig. 69), the pressure drop is 1 v. or less, and mercurous nitrate is used as an electrolyte. The product of electrolysis is mercury and no gas is liberated. Current passes from D, through a fine wire-resistance cell P to the mercury anode A, thence to the hollow platinum cone C and the negative terminal E. F is the mercury reservoir and R is a shunt of such resistance that only about 1/200 of the main current passes through the meter circuit. Mercury collecting on C falls into G, and so into the U-tube, which is calibrated in B.O.T. units. The U-tube is just filled by the passage of (100/V) amp.-hrs. and the mercury then siphons into a larger tube calibrated in 100's of B.O.T. units. To reset the meter, it is tilted so that the mercury returns to F. In the *Holden* electrolytic meter, depending on the transference of hydrogen from one part of the meter to another, only 1/50000 of the main current passes through the electrolyte. The error of

a shunted electrolytic meter should be not greater than $\pm$ 2 per cent. at all loads.

The only *unbraked motor meter* is the O'Keenan amp.-hr. commutator meter; the driving torque is balanced solely by the resisting torque due to the back e.m.f. of the armature winding. The latter rotates in the field of a permanent magnet and is connected to a shunt traversed by the current to be metered. An armature current of about 4 milli-ampères is required to overcome the total frictional resistance, 90 per cent. of which lies between the commutator and brushes. The meter will start at 1/150 full load if uncompensated or at 1/500 load if compen-

FIG. 70.

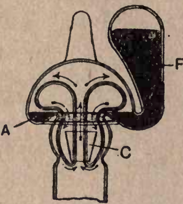
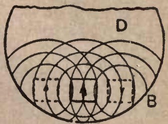


FIG. 72.



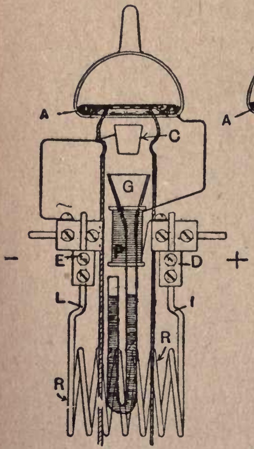


FIG. 69.

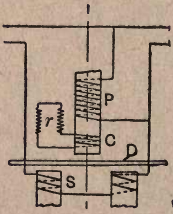


FIG. 71.

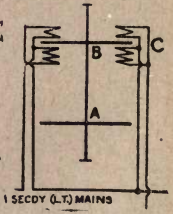


FIG. 73.

sated by a small constant shunt current through the armature. By using a brush frame oscillating to and fro perpendicularly to the meter axis, brush friction may be entirely eliminated and, by a special bridge connection, the O.K. meter can be made to record watt-hrs. In *braked* ampère-hour meters, a metal carcass is mounted on the spindle and, rotating in a magnetic field, is subject to a braking torque increasing with the speed. The armature current therefore increases almost proportionally with the speed—a circumstance which hastens deterioration of the commutator and brushes.

In *mercury meters* a disc or bell of copper is submerged in a mercury bath in a magnetic field and traversed radially by the current to be measured; most of the current passes through the armature disc in preference to the higher resistance mercury path. There are numerous modifications in materials and construction of the mercury receptacle and armature. Though this type of meter can be used for A.C. measurements, meters of the induction type are generally preferred for the latter. When arranged for ampère-hour measurements, the meter may have either permanent magnets or a series wound (current) electromagnet to provide the armature field. Using permanent magnets, the braking $\propto$ speed, and speed $\propto$ current. A compensating coil corrects for fluid friction (which $\propto$ (speed)^2) at high speeds. Gradual weakening of the magnets introduces certain errors, but these cancel to some extent, since both driving and braking torques are reduced. Using a series electromagnet to produce the field, the torque $\propto$ (current)^2, and fluid friction ($\propto$ (speed)^2) is used for braking, so that speed $\propto$ current. When arranged for watt-hour measurements, the motor field is produced by a shunt coil on a laminated field system. Then the torque $\propto$ power, and the braking and compensating devices are such that the speed $\propto$ torque. The *advantages* of mercury meters include absence of commutator; direct passage of moderate currents through the meter; small pivot friction due to the armature being floated in mercury; low starting load. On the other hand, the use of mercury involves special precautions in transit and the axial play in the spindle leads to hammering of bearings. At very low loads change in the armature friction law introduces error, whilst at very high loads there is heating in the mercury and possibly some distortion of the armature disc. Owing to the low armature resistance, a low resistance shunt may be employed, and this is an important consideration when very heavy currents have to be metered. Shunts are convenient in such cases, but variations in Hg. resistance, or even partial leakage of the mercury, may introduce serious errors. Where shunts are used, the construction of the meter may be much lighter, and heating of the mercury is reduced. The meters referred to in this paragraph form roughly 85 per cent. of the number now used in London; they are available down to $1\frac{1}{2}$, $2\frac{1}{2}$ and 3 amps. capacity and guaranteed to be accurate with $\pm$ 2 per cent., and to start on 1 per cent. of full load.

II.—D.C. and A.C. Types.—The *Thomson* meter consists essentially of an ironless electric motor, the field coils of which are traversed by the current metered while the armature winding is placed in series with a high resistance across the supply mains. Any commutator sparking is at the full supply voltage and is

specially destructive. An auxiliary coil provides a friction compensating torque which increases, however, with the *square* of the supply voltage. An uncompensated meter of this type starts at 1/75 or even 1/50 load. A special disadvantage is the effect of the earth's field; according to the orientation of the meter, the error due to this cause may be $\pm 4-6$ per cent. at 1/20 load. The adjustment of the meter needs great care, and calibration *in situ* is almost imperative. On a.c., the meter is independent of voltage and frequency variations, but induction meters offer great practical advantages.

Recent improvements in C.C. watt-hr. meters are :—Better design of flat disc-armatures of astatic type, using few (*i. e.* wide-angle) sector-coils to reduce interference and obtain powerful driving torque; also the use of an electromagnetic recording train to eliminate the frictional resistance of an ordinary geared-train which is a very serious factor at light loads. The resistance of a " cyclometer " train, when several figures are due to change at once, may hold the meter stationary on very light loads.

The *Aron* meter is the most accurate extant, but it is complex and costly, liable to mechanical derangement and difficult to calibrate. Its action depends on the difference between the number of swings of two pendulums carrying shunt-excited bobbins and respectively accelerated and retarded by the field due to fixed bobbins carrying the current to be metered.

III.—A.C. Meters.—The complete theory of *induction meters* is complex, but the construction and action are so simple and satisfactory, that these instruments are used almost exclusively for a.c. circuits. Referring to Fig. 71 P is the potential-, S the series-, and C the compensating-coil. The alternating fluxes produced under these poles establish currents, as shown at B Fig. 72. P is highly inductive, but S is almost non-inductive, so that the fluxes due to these two coils are practically in quadrature, and the disc eddy currents due to P are a maximum when the flux under S is maximum and *vice versa*, so that a torque is produced on D which varies with the power supplied to the load, providing the currents P, S are in quadrature at unity power factor. Exact quadrature is secured by the compensating circuit C; the adjustment of the latter for a given supply frequency is sufficiently accurate (for commercial purposes) over 10 per cent. variation of frequency. Owing to the great effect of frequency and wave form, induction meters should be calibrated under the conditions in which they are to be used. Temperature errors are negligible, but 20 per cent. voltage variation produces 1·5–2·5 per cent. meter error, and 3 per cent. frequency variation produces 1 per cent. meter error.

Meter Transformers: H.T. Meters.—Ordinary meters in conjunction with instrument transformers may be used to record energy consumption at heavy current, high voltage, or both. The transformers must be designed liberally, well constructed, and moderately loaded on the secondary side. Meters must be calibrated with their own transformers and re-calibrated if any important variation occurs in the normal load or its power factor.

Energy delivered at high tension may be metered by a l.t. meter utilising the main (consumer's) transformer, instead of instrument transformers. The principle is illustrated in Fig. 73. An armature A, with the usual field coils (omitted for clearness), measures energy delivered from the l.t. terminals of the transformer. A second armature B on the same spindle is driven by coils C, D connected as shown and adjusted so that the torque due to CC records the light load losses in the transformer. The coils DD record the transformer copper losses *not* included in the light load loss. The same principle is applicable to polyphase circuits. It is generally best to provide each consumer's transformer with its own meter. This type of meter is inexpensive and capable of very accurate adjustment and compensation. The coils C, D can be adjusted so that the meter, placed anywhere in the l.t. circuit, records energy passing any stated point in the h.t. or l.t. line. This permits of any tariff-basis and is specially useful in linked networks.

Meter Accuracy; Location; Testing.—Legal requirements as to meter accuracy prescribe an error not greater than $\pm$ 2 per cent. in meters of over 3a. capacity ($\pm$ 3 per cent. in meters of less than 3a. capacity), at all loads between 1/10 and full load and under normal supply conditions and unity power factor (if a.c.); $\pm$ 10 per cent. frequency change at 1/2 load must not introduce a greater error than $\pm$ 2 per cent. in a.c. meters; and no meter must "creep" on no load, even though subject to a supply pressure 10 per cent. above normal. In laboratory tests, the true energy or quantity supply to the test circuit is usually determined by indicating instruments and thence a "*testing constant*" (= revs. of meter spindle per 1000 watt-hrs., *or* such other quantity as the maker may specify) is determined and stamped on the meter case or frame. *Rotating standard meters* are very convenient for testing meters *in situ*. Meters should always be tested with the cover in place, the temperature of the working parts being chiefly determined by the meter losses. Instead of taking current from mains through rheostats when testing c.c. meters *in situ*, portable accumulators may be used. Nickel cells are lightest. Cost of test is reduced and steadier current control obtained. Meters up to 4000 amps. have been so tested.

It is worth while devoting care to the *location* of meters; damp spots or places subject to wide extremes of temperature should be avoided. The meter should be easily accessible at all times and should be firmly fastened to a rigid support. Many meters have cases which are not dust-proof, and in some cases spiders and beetles can gain access to the working parts. Thomson meters must be located away from stray fields.

Owing to the serious loss of revenue or injustice to consumers caused by even a small percentage meter error, all meters should be tested *in situ* at regular intervals which, on 100–200 v. circuits, may vary from one to two years in the case of consumers paying £5 or less per annum, down to two or three months in the case of large power consumers. Ampère-hr. meters with silver commutators may be visited annually and, after the commutator has been cleaned with linen tape, the starting-load of the meter is determined; if this is unsatisfactory, the bearing jewel is changed and, as a last resort, the meter is returned to the station laboratory. Ampère-hr. meters with gold commutators may be visited once in two years, and the commutator only cleaned when test shows it to be desirable. Thomson-meter commutators should be cleaned three times per annum, the starting-load being checked at the same time; once a year a complete test *in situ* should be effected. Induction meters should be tested every one or two years, according to size, and Aron meters should be tested annually by a standard meter. About 50 per cent. of commutator meters run too slowly on low loads; too great pressure of the brushes on the commutator may lead to 10 per cent. error on 1/10 load, and a short between two bars may stop the meter on low loads and cause — 10 per cent. error on full load. The accuracy of tests *in situ* is about half that of laboratory tests; even the latter cannot be guaranteed within $\pm$ 0·5 per cent. Tests on nearly 90,000 meters of various types in use in New York (1911), showed 14·5 per cent. to be over 4 per cent. slow; 5·5 per cent. to be over 4 per cent. fast, and 80 per cent. to be correct within $\pm$ 4 per cent. *Polyphase meters* were found to be *wrongly connected* in half the cases in which complaints were received as to their accuracy. The speed ratio of the single-phase elements in a three-phase meter of this type affords a check on the accuracy of the connections, providing the p.f. of the load metered be known approximately. If the line p.f. is over 0·5, the meter should run forward when each of the shunt circuits are opened in turn; if the p.f. is less than 0·5, one element should run backwards and the faster one should run forwards.

Special Meters.—For maximum economy of generation of electrical energy, the load on the central station should be as nearly constant as possible and, with a view to making it to the

pecuniary benefit of the consumer to aid in attaining this result, innumerable variable supply tariffs have been devised and special meters have been evolved to enable their application. The well-known Wright *maximum demand* tariff uses any ordinary meter in conjunction with a thermal or ball-type maximum-demand indicator. In the Siemens maximum-demand meter, a pointer moves over a dial (additional to the usual recording train), and indicates the maximum demand, which has been averaged during fifteen, thirty, or sixty min. periods as the case may be. *Current limiters* are used to interrupt supply (either intermittently, so as to cause flickering of lamps, or absolutely), so long as the demand in the circuit controlled exceeds that predetermined value up to which unlimited supply is allowed at a fixed charge per annum. Supply beyond this maximum demand may be arranged for, in which case a *peak-meter* is installed, in place of the current limiter, and this commences to record (with or without a warning signal), when the contract demand is exceeded. *Double-tariff meters* stimulate day loads by changing over from one recording train to another at predetermined hours; the records on the two trains are charged at different rates. *Multiple-tariff* meters extend this principle by recording the total payment due according to a special tariff scale which is fixed in advance for every hour of the day.

SCOPE AND ERRORS OF MEASURING INSTRUMENTS.

Moving iron instruments show greater or less hysteresis error; their indication is too high on a decreasing pressure or current. Their initial accuracy is high and is little affected by frequency and temperature, but error due to stray fields must be prevented by internal laminated iron shields. Some makes are rather delicate; most are easy to repair. Scale length is short, and ratio ot torque to weight of moving parts low. *Moving coil permanent field* instruments are only applicable to d.c. measurements, but are then the best type available. Moving coil instruments of the *dynamometer* type are applicable to d.c. and a.c. instruments; the older types are sensitive to stray fields, particularly (in a.c. instruments) if the frequency of the field is the same as that of the current measured; frequency and temperature errors are low. In general, moving coil instruments have very high initial accuracy ; short scale length and low (torque/weight) ratio. Their repair is difficult. *Induction* instruments are essentially a.c. instruments, and are very popular for

switchboard and general commercial use. Their high initial accuracy is well maintained during working; their construction is simple and strong, and their repair easy. 300° scales are easily provided; temperature errors can be closely compensated; stray fields of supply frequency introduce small errors; frequency error is high, but is of little importance in central station-work, owing to the constancy of modern supply frequency. Hot-wire apparatus is equally accurate in d.c and a.c. circuits, and electrostatic voltmeters are independent of frequency and wave form. Controlling springs weaken with age, leading to positive errors, which are, in some cases, offset by weakening of the permanent field magnets. Temperature errors may be reduced by avoiding copper windings or by swamping or compensating the temperature variation of resistance of the latter by coils of zero or negative temperature coefficient metal. According to Edgcumbe, *good commercial instruments* may be expected to give the following maximum errors :—

	Per cent.
Wheatstone Bridge ; P.O. Pattern	0·1-0·2
Wheatstone Bridge ; Self-contained, portable	0·5-1·0
Deflectional Insulation Indicator	3·0
Potentiometer	0·03-0·1
Moving-coil Voltmeter	0·4-0·75
,, Ammeter	0·5-1·5
Moving Iron Voltmeter	0·5-1·5
,, Ammeter	0·5-2·0
Induction Voltmeter	1·5
,, Ammeter	2·0
,, Wattmeter	2·5

	Per cent.
Dynamometer V.meter	0·4-0·75
,, Ammeter	1·0-1·5
,, Wattmeter	1·0-1·5
Hot-wire Voltmeter	1·5
,, Ammeter	2·0
Electrostatic Voltmeter	0·8-1·5
Dynamometer P.F. Indicator	2·0
Recording Instruments (pen-and-ink type)	2·5-3·0
Recording Instruments (inkless)	1·0-2·0

See also Edgcumbe—*loc. cit.*

Purely electrical errors can be very closely compensated in switchboard instruments. Mechanical errors, which increase with the age of the instrument, must be carefully avoided. The moving system should not be so heavy as to subject the bearing jewels to excessive wear, but very light movements are necessarily delicate, easily damaged, and susceptible to errors caused by electrostatic attraction.

MEASURING POWER FACTOR.

In the Weston power factor meter the main current flows through oval stationary coils. The moving system comprises two circular coils on the same staff; it is essential that these windings be of equal magnetic strength and accurately at right

angles to each other. In polyphase circuits the moving coils are connected across loads in which the e.m.f. differs in time-phase, and in single-phase systems a phase-splitting device is used, as in Fig. 74. When the current in one of the moving coils is in phase with that in the fixed coil, the former will place itself parallel to the latter. If the current in the fixed coil is to any degree out of phase with the current in either of the moving coils, the latter take up a position which is a measure of the phase angle or of the power factor. The instrument is independent of any commercial variations in frequency, wave form, or temperature; but cannot be used for general testing purposes where frequency and wave form are widely variable. In the Edgcumbe power factor meter for balanced three-phase systems, the position of a three-phase star-wound moving coil with respect to a

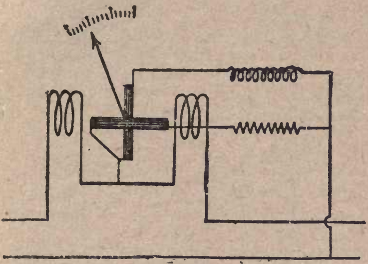


FIG. 74.

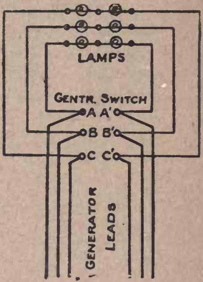


FIG. 75.

stationary current coil depends on and is taken as a measure of power factor. Since the phase displacement does not depend on a choking coil, this instrument is independent of frequency, wave form, and voltage. A very convenient method of estimating three-phase power factors approximately is to determine the relative speeds of the two single-phase elements of a suitable three-phase meter connected in the circuit, and thence determine the corresponding power factors by interpolation of a graph plotted from the following data :—*Ratio of Element Speeds*+ 1·000, 0·816, 0·633, 0·500, 0·347; 0·185; zero; —0·226; —0·533; —1·000. *Three-Phase Power Factors*—1·000; 0·985; 0·940; 0·867; 0·766; 0·643; 0·500; 0·342; 0·114; zero. It must be noted that this method is only applicable if the meter connections are correct.

PHASE SEQUENCE, ETC.

The first step in arranging alternators for parallel operation is to "phase out" the leads so that the phases of one machine are connected to the corresponding phases of the others when the paralleling switch is closed. Unless the phase connections are correct, the incoming generator is placed more or less in series with the others and there are disastrous circulating currents. Referring to Fig. 75 the generator switch is connected tentatively; and lamps are connected between the switch terminals, the aggregate voltage of lamps in each phase being about $1\frac{1}{2}$ times the circuit voltage. The generators being run at near synchronism, the phasing is correct if all the lamps flash (and darken) simultaneously. If this does not occur a fresh combination of connections must be tested.

A simple device for checking the sequence of three-phase connections consists of a wooden ring provided with a con-

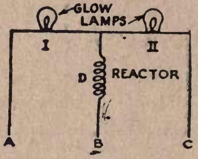


FIG. 76.

tinuous and uniformly distributed winding of a few dozen turns of insulated wire. Tappings are taken from equidistant points through lamp sockets to terminals which are connected to the three-phase lines. A compass is placed at the centre of the ring and in the plane of the latter. When the sequence of connections is correct, the compass needle rotates and indicates the direction of the rotating field. The lamps used in the sockets should be rated at not less than half the voltage between three-phase lines.

Varley's method of determining phase rotation, consists in connecting two incandescent lamps and a reactance or condenser in star, and noting the relative brilliancy of the lamps. If lamps and reactor be connected to a three-phase supply ABC (Fig. 76) relative dimming of lamp I indicates that the phase rotation is clockwise; whilst if lamp II be the dimmer, the phase rotation is counterclockwise. When a condenser is used instead of the reactance D (Fig. 76) the significance of the lamp dimming is reversed, *e. g.* lamp I dim then means that phase rotation is

counterclockwise. This method of phasing out is also applicable to two-phase circuits. For use where cables, motors, transformers, etc., have to be reconnected frequently, the lamps and reactor may be mounted on a board.

Kapp suggests the following method of determining phase sequence and whether there is lead or lag in three-phase current. The current coil of the wattmeter is connected in one phase (A) and the shunt coil is connected between A and another phase (B), the reading being then W_b. With the shunt coil connected between A and the third phase (C), the reading is W_c. A condenser is then connected in the shunt circuit, a suitable capacity being (12000/R) mfd. if the supply frequency be 50 cycles and the resistance of the wattmeter shunt circuit be R ohms. Repetition of the above observations yields readings W'_b and W'_c. The four values of W are interpreted as follows :—

If readings without condenser give	$W_c > W_b$		$W_b > W_c$	
and with condenser give .	$W_b > W'_b$	$W'_b > W_b$	$W'_c > W_c$	$W_c > W'_c$
the phase sequence is . .	ABC	CBA	ABC	CBA
and the current	lags	leads	leads	lags

The sign of the reading must be taken into account, *e. g.* if W_b is numerically less than W'_b, but the latter is negative, then W_b is taken to be the greater.

OHMMETERS.

Ohmmeters are direct reading instruments automatically evaluating the ratio R = (Pressure/Current). The "*Megger*" testing set (Fig. 77), contains an ohmmeter and magneto-generator (100–1000 v.) in one box, the same pair of permanent magnets serving both ohmmeter and generator. The latter is a d.c. machine, and the gearing has been arranged to ensure constant speed (and therefore testing pressure). The pressure coil P of the ohmmeter and the current coil AA are free to rotate in the field N S. The pressure coil is wound on one side of the cylindrical core I and the current coil is wound entirely outside I. A compensating coil outside P, and connected in series with it, protects the latter from external influences. The line and earth terminals are as shown L, E. On running G, the pressure coil takes the position shown when there is no connection between L, E, or when the line resistance is infinite. When, however,

a line leakage current flows through A A, the moving system rotates till finally, when there is no current through P (dead short on L—E), the insulation indication is "Zero." The "*Bridge-Megger*" is a similar instrument used in conjunction with a direct-reading resistance box. The instrument may be used as a "*Megger*" for insulation measurements (5000 ohms. to 40 megohms.), or by means of a change-over switch, the ohmmeter may be used as a galvanometer, and resistances from 1 ohm. to 1 megohm. rapidly determined.

In Nalder and Thompson's "*Ohmmer*," the generator and ohmmeter are still in one case, but the ohmmeter is now an electrostatic instrument (Fig. 78). A vertical spindle carries thirteen parallel vanes (about 0·3 in. apart), working into four sets of

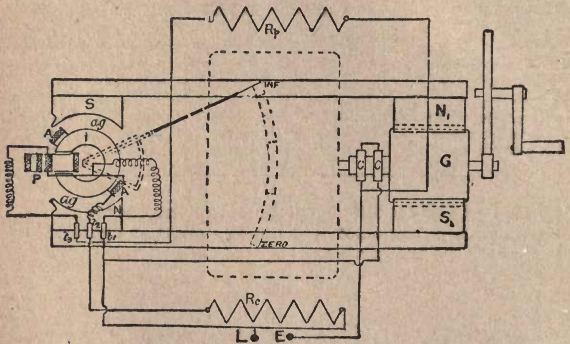


FIG. 77.

shaped fixed inductors. The vanes are of mica covered with aluminium. One of the generator terminals is connected directly to the quadrant A, and also, through a resistance R wound on porcelain and mounted in the case, to the other quadrant B and the line terminal. The only terminal of the generator is connected to the moving vanes V and to the earth terminal. So long as no current passes between L and E, the vane V lies symmetrically between A, B, and the pointer shows infinite insulation resistance. When a leakage current flows through the external circuit, there is a fall of potential across R, and V takes up a position determined by its shape and the p.d. between A, B. The instrument is quite unaffected by stray fields.

Evershed's "*Ducter*" is a portable instrument enabling the direct measurement of resistance between 10 microhms and

5 ohms. Paul's "*Ampall*" set, while primarily designed for the measurement of currents of practically any magnitude (without

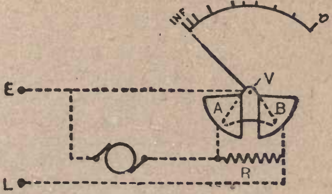


FIG. 78.

opening the main circuit for any test connections), is applicable to resistance measurements and the determination of pressure drop at switch contacts, and so on.

SYNCHRONISING ALTERNATORS.

In order that two alternators may be connected in parallel their voltages and frequencies must be identical and their voltages exactly in phase. Otherwise, heavy "cross currents" flow between the two machines. Electro-magnetic action tends to pull machines into step when the phase difference is not great, and to keep them in step once they are synchronised. If the wave forms of two generators are not identical, cross currents flow between them during operation in parallel. Such currents involve waste of power and cause heating, "hunting" and voltage fluctuation. Fluctuations in driving torque will produce circulating or cross currents and finally pull the machines out of step; certain electrical conditions produce the same effect. It is difficult to get machines exactly and permanently in synchronism before paralleling. The incoming machine should be switched in just before it reaches instantaneous synchronism and while it is slightly ahead of the others. It then drops smoothly into phase as it takes up load.

Synchronising by Lamps.—Lamps may be used to indicate voltage synchronism. Referring to Fig. 75, when the lamps are all dark, the potentials of AA^1, BB^1, CC^1 are the same at every moment and the paralleling switch may be closed. In Fig. 79 when the generators AB are in synchronism, there is no p.d. between *aa′* hence the lamp L remains dark. A second

lamp L′ connected between bb^1 covers the risk of false indication of synchronism by breakage of filament in L. This constitutes the "synchronising-dark" method. In order to "synchronise-light" the lamp L is connected between a and b^1 and the machines are in synchronism when the lamp glows most brightly; this moment is not always easy to determine. Using the synchronism-dark method, the dark period may be shortened, and hence determined more accurately by using lamps of less than twice the generator voltage. The following argument in favour of synchronising-dark is due to F. A. Robbins. Referring to Fig. 80 the voltage across the lamp in the synchronising-dark method is OC the vector sum of the alternator e.m.f.'s OA, OB. When synchronising-light, the lamp voltage AB is the vector difference of the e.m.f.'s OA, OB. A small phase difference yields a relatively large value of OC, whereas a larger phase

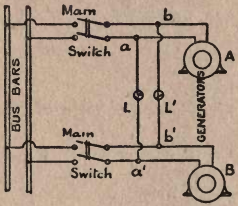


FIG. 79.

difference is needed before AB differs much from OA + OB. The smallest phase difference which can be detected by the dark method is 29° with carbon and $9\frac{1}{2}$° with tungsten lamps; and by the light method is 28° with carbon and 42° with tungsten lamps. The percentage of normal voltage needed to make a filament luminous is 25% for carbon and 8% for tungsten. The percentage decrease in voltage to produce distinct dimming is 3% for carbon and 6% for tungsten lamps. Carbon lamps should be used for light and tungsten for dark synchronising. The most sensitive arrangement is the dark method using tungsten lamps. Instead of lamps, a voltmeter may be used, synchronism being reached when there is no p.d. between aa' Fig. 79. With high voltage generators, pressure transformers are used in the synchronising circuit.

Synchroscopes.—Synchronising lamps yield only an approximate indication of synchronism and the frequency of flicker gives only a rough indication of the frequency error in the incoming

machine. The lamps do not show whether the incoming machine is too fast or too slow, or by how much it is out of phase.

To give exact information on these points and to respond more quickly to frequency and phase changes, a synchroscope must be used. This is usually arranged with a really or apparently rotating pointer, the speed of which decreases as synchronism is approached. By the rate of motion of the pointer and its position when stationary, the difference respectively in frequency and phase can be determined. The synchroscope is generally mounted with the necessary synchronising voltmeters on a special pedestal or switchboard bracket. *Rotary Synchroscopes.*—The Everett-Edgcumbe rotary synchroscope uses a small two-phase induction motor, the stator of which is connected to the busbars and the rotor to the incoming machine. A phase-splitting device in the stator circuit produces two-phase current and hence two rotating fields. Until synchronism is reached, the rotor runs at a speed and in a direction determined

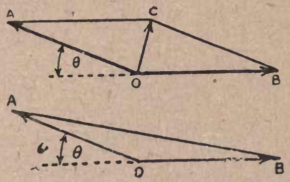


FIG. 86.

by the difference in frequency between the line and generator e.m.f.'s. Directly equal frequency is reached, the instrument acts as a phase indicator, and at synchronism the pointer attached to the rotor remains stationary in the centre of the scale. This synchroniser is necessary in one phase only and can be combined with a synchronising lamp and red and green signal lamps showing whether machine is too fast or too slow. In h.t. circuits one transformer is required for each alternator and one for the busbar circuit.

Weston Synchroscope.—This is an ingenious combination of a synchronising lamp and indicating phase meter. The latter comprises a dynamometer wattmeter, the moving system of which is connected to a condenser across the terminals of the incoming generator. The stationary coil is connected to resistance across the line. By adjusting the capacity and inductive resistance of the two circuits, the currents in the moving and stationary coils are brought into exact quadrature when the

e.m.f.'s are in phase or antiphase. The pointer then remains stationary at the centre of the scale. If the e.m.f.'s are in phase or antiphase, the pointer stands to left or right of zero, and if the incoming and line frequencies are equal the pointer swings. To discriminate "antiphase" from "inphase," the pointer is placed behind an opalescent screen and its shadow is visible as thrown by a lamp which glows only when the e.m.f.'s are coincident in phase. Till synchronism is achieved, the flashing lamp shows the pointer apparently to be rotated in one direction or the other (fast or slow), and when synchronism is attained the pointer is shown steady at zero. Phase coincidence within 1° is guaranteed over a wide range of voltage and frequency.

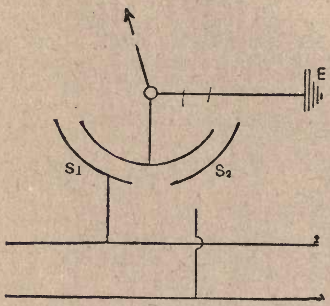


FIG. 81.

The moving parts are light and simple and there are no sliding contacts or brakes.

Synchronising Voltmeters.—Synchroscopes take no account of equality of voltage of line and incoming machines. Separate voltmeters may be mounted on the same pedestal or bracket as the synchroscope, or a single instrument with two pointers may be used. A centre zero or differential voltmeter is more convenient and eliminates possibility of instrument errors indicating falsely equality of pressure. The scale should be open at low readings so that pressure equality can be determined accurately.

Fault and Leakage Indicators.—The development of leakage indicators has been stimulated by the Home Office Rule that electrical installations in coal mines must be provided with an instrument which will continuously indicate the state of insulation.

of the mains. For h.t. single-phase circuits, an electrostatic indicator, such as shown in Fig. 81, may be used for relative indications. So long as the insulation of the two mains is of equal resistance, the pointer lies centrally on its scale, but when the resistances are unequal, the vane is deflected to one side or the other, and the pointer shows the ratio between the insulation resistance of the two lines. Fig. 82 shows the Nalder-Thompson recorder and leakage current indicator in use in an unearthed three-phase system. The choking coil limits the a.c. flow to earth in case of a bad fault, and direct current from a 50v. battery or exciter flows between the a.c. mains and earth, and operates the permanent magnet recorder and relay instruments. The recorder operates on the tapping principle, and is calibrated

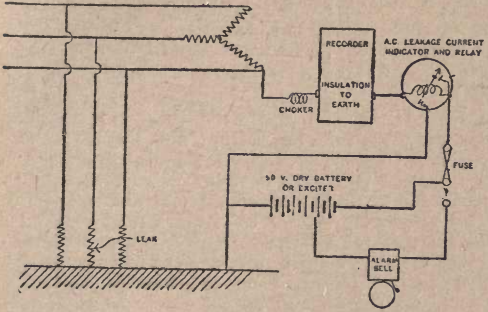


FIG. 82.

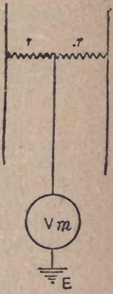


FIG. 83.

in megohms. The relay instrument is calibrated to indicate the maximum a.c. leakage current flowing from main to main consistent with the resistance recorded at any moment. If the insulation resistance falls below a predetermined limit, the relay makes contact, with the result that the fuse wire holding up the spring contact A is placed straight across the battery and at once blown; the leakage instruments are thus placed temporarily out of circuit and a loud alarm bell is rung. In two-wire l.t. circuits (d.c. or a.c.) a resistance r r (Fig. 83) may be connected between the mains and a voltmeter connected to earth from its centre point. The voltmeter indicates the relative insulation resistance of the mains and in d.c. circuits the actual insulation resistance may satisfactorily be determined by connecting the voltmeter to each main in turn.

ELECTRIC LAMPS.

Incandescent Lamps.—The filament may be of carbon, metal or a mixture of rare earths, and is mounted in a clear, translucent or coloured globe in which—in all but oxide filament and nitrogen-filled tungsten lamps—a vacuum is produced by mechanical or mercury pumps.

Large numbers of carbon filament lamps are still used for special purposes, but the tungsten lamp is now the standard for all ordinary services where filament lamps are employed. Since 220–250 v. tungsten lamps are about 20 per cent. dearer than 110–125 v. lamps; have a shorter life; and yield only 90 per cent. as much light for equal watts, it is advisable to use the lower voltage lamps where possible. In many cases it would pay to install a balance coil or motor generator to allow lower voltage lamps to be used.

Much higher efficiency than one watt per candle can be obtained by overrunning ordinary tungsten lamps, but the life of the latter is then reduced by blackening and disintegration of the filament. By filling the bulb with nitrogen, filament disintegration is prevented; and by using a relatively thick filament wound as a close spiral of small diameter, heat loss by convection is reduced. Convection loss increases approximately with the 1·5th power of the filament temperature, but the radiated energy increases with the 4·7th power of the temperature, and in a nitrogen filled tungsten lamp built on the above principle and working at 2500° C. (*cf.* 1850° C. in one-watt lamp) the power consumption can be reduced to half a watt per candle. Remarkable progress has been made in developing low candle-power, high voltage nitrogen-tungsten lamps (as small sizes as 120 c.p. being available for 100–130 volts circuit), but it is probable that the auto-transformer will have a fresh lease of life in house lighting, for it seems unlikely that 25–50 c.p. half-watt lamps can be built for 200–260 volt circuits. The considerable pressure reduction necessary in such cases may introduce special wiring problems owing to the relatively heavy current on the low pressure side of the transformer. The high efficiency of the new lamps makes possible (economically) the use of a 100 c.p. or larger unit in an indirect or semi-indirect fitting in domestic lighting. Low voltage half-watt lamps are on the market for use in motor headlights, etc., and these lamps are useful for a number of other special optical purposes. The *arc-incandescent* lamp is of high efficiency and is specially useful in optical applications. A tungsten filament

being first raised to incandescence, the negative discharge from it starts an arc between the filament and a small tungsten ball which is mounted on a bi-metal strip. The latter is buckled by heat conducted from the arc and the tungsten ball is thus drawn along the filament away from the striking-point. The lamp has an ordinary spherical bulb filled with nitrogen; and it is used with a ballast resistance to secure steady running and to adapt it to various voltages. The standard equipment is rated at 100 c.p. and provided with resistance steps to suit 100, 110, 200, 220, or 240 v. supply. The intrinsic brilliance of the tungsten crater is 10,000 c.p. per sq. in. at 0·5 watt and 30,000 c.p. per sq. in. at 0·33 watt per c.p.

Overshooting.—According to C. J. Berry the ratio of hot to cold filament resistance is :—Ordinary carbon ½ : 1. Metallised carbon 1½ : 1. Tantalum 6½ : 1. Tungsten 11½ : 1 (vacuum lamp); 14½ : 1 (gas filled). The ratio of initial : normal current is lower than the cold : hot resistance ratio owing to reactance and line resistance drop. The actual current ratio in a 75 watt gas-filled tungsten lamp is 12 : 1, and in a 1000 watt lamp is 7 : 1. The maximum initial current is reached in 0·0004 to 0·003 sec.; and the normal current in 0·1 to 0·2 sec. Much the same overshooting occurs with a.c. as with d.c., and it should never cause properly selected fuses or circuit-breakers to operate.

Arc Lamps.—On separating the tips of two carbon rods, which have been pressed together and brought to red heat at the contact point by the passage of electric current—a conducting " arc " of carbon vapour is formed between them and, *subject to the provision of at least a certain critical voltage between the tips*, and suitable regulation of the distance between the latter, this arc is steadily maintained. The minimum or " critical " voltage necessary is 35–40 v. for the carbon arc and 30 v. for the magnetite arc. The current taken by a carbon arc increases with decreasing terminal p.d., hence a ballast resistance (or inductance on a.c. circuits) is necessary to obtain stable operation. On direct current supply, the positive carbon tip forms a highly incandescent crater, the negative tip having a smaller and less brilliant " bright spot." On alternating current supply, both tips are equally incandescent (*see* Fig. 90). In the d.c. open arc, using plain carbons, about 85 per cent. of the total light comes from the positive crater, about 10 per cent. from the negative tip, and only 5 per cent. from the arc itself. To steady the arc, it is usual to " core " one or both carbons with a softer and purer grade of carbon.

By surrounding an " open " arc by an air-tight globe, an " enclosed " arc is obtained. The critical voltage and stable length of the arc are much increased and, wastage of the carbons by mere burning-in-air being prevented, the burning hours per trim are greatly extended.

TABLE III.—AVERAGE CHARACTERISTICS OF VARIOUS ELECTRIC LAMPS.

	Range.			Watts per		Life.		% C.P. Decay in Life.	Carbons. ‡			Burning Hours.	Height of Suspension.
	Volts.	Amps. or Watts.	C.P.*	Mhcp.	Mh-scp.	Mean	Maximum.		No. Prs.	Usual Length. Pos.	Neg.		
Filament.		watts.	mhcp.							Inches.			
Carbon	25-300	30-1000	8-300	3½-4	..	800§	2000	20-30	..	..	..	..	8 to 15 ft.
Met. Carbon	25-200	20-150	8-50	2-3	..	500-600	1500	20	..	..	..	..	
Nernst	50-250	¼-3 amp.	50-600	1·5	..	400-800	1500	30-50	..	..	..	..	
Tantalum	20-250	20-450	10-200	1·7-2·2	..	1000	3-5000	15-20	..	..	..	..	
Tungsten (Colloid)	25-260	25-1000	20-900	1·2-1·3	..	2000‖	8-10000	5-10	..	..	..	..	
Tungsten (Drawn)	25-260	25-900	20-1000	0·8-1·3	..	2000	8-10000	5-7	..	..	..	..	
,, N_2 filled	25-260	15-1500	30-3000	0·5	0·5	See ¶¶		10 20	..	..	..	..	15-40
Arcs.		amps.	mhscp.			Arc Length.							
Open D C.	40–50	5-15	400-1200	..	1·0-1·5	⅛in.-¼in.		..	1 or 2	8-12	8-12	10-20	15ft. (low ct.
,, A.C.	40–45	8-15	350-700	..	1·5-2·0 †	⅛in.-¼in.		..	1 or 2	8-12	8-12	10-20	20-30ft.
Enclosed	70-80	3½-10	400-900	..	1·0-2·0	½in.-1in.		..	1 or 2	12	4-6	50-150 ¶	(ordinary)
Open fl. Inclined	35-50	8-15	1000-4000	..	0·2-0·3 ††	½in.-¾in.		..	1, 2, 4 or 10	16-24	16-24	10-20 **	50-60ft.
Open fl. "Axis."	30-40	5-15	1000-2500	..	0·2-0·45 ††	..		..	1	8-15	8-15	10-25	(largest
Enclosed Flame	50-100	4-8	2000-3000	..	0·2	¾in.		..	1	8	18	60-80	lamps and
Magnetite	60-70	4	500-800	..	0·6-0·8	1in.		..	1	..	12	150	open spaces)
Cooper-Hewitt	50-500	3½	500-1000	..	0·33-0·5	20in.-44in.		7-10	..	..	..	3-4000*	8-30ft.
‡‡ Slca. Hg.	100-600	1½-6	800-3000	..	·20-·30	2½in.-4 in.		7-10	..	..	..	3-4000*	12-80ft.
§§ Moore	10000-12000	0·3	15/ft. run	..	1·7(N_2)-3(CO_2)	100-200ft.		..	..	..	..	..	20-30ft.
‖‖ Neon	1070	1·1	60/ft. run	..	0·4-0·9	18-20ft. ‖‖		..	..	..	..	..	20-40ft.

* C.P. of arcs varies with current (approx.); carbon arcs regulate automatically for voltage; mercury lamp stands 10% voltage variation without appreciable effect. † Wave form appreciably affects efficiency of A.C. arcs. ‡ Space forbids detailed treatment of carbon size. § Economical to smash carbon lamps when c.p. falls to 80% initial (*i.e.* after 800-1000 hours); smashing point of wire lamps theoretically reached when c.p. decays by 3%-5%. It is impracticable to ascertain this limit with accuracy, hence lamps should be run to destruction. The life of carbon and tungsten lamps varies with 3½-4th power of initial w./c.p. High voltage, low c.p. wire lamps are best run on d.c.; life of Tantalum lamps is about 750 hours on a.c. ‖ Recent statistics of street lighting in Hammersmith show 3500 burning hours for Tungsten lamps. ¶ May rise to 300 hours, but globe obscuration is then serious. ** Five hours in magazine lamps. †† According to colour; higher efficiency applies to D.C. yellow, lower to A.C. white; for same colour, A.C. consumption is 10-20% the higher. General effect of A.C. arc supply is 90% burning hours and 50-80% candle power. ‡‡ Guaranteed life of mercury lamps is 1000 hours; average 3000-4000: maximum over 10,000. §§ Cleaning and re-exhaustion necessary after, say, 10,000 hours. ‖‖ Longer tubes give the higher efficiency: voltage 3200 for three 6m. tubes in series. ¶¶ 800 hrs. guaranteed; 1000 to 2000 averaged in many installations; maximum probably about 3000 hrs. Special fittings for best results.

Weight of arc lamps complete varies from 10-40 or 50 lb., according to type and size.
Current consumption of any lamp in amps.—(candle-power × watts per c.p.) / voltage.

In the "flame" arc, the carbons are impregnated with such chemicals as calcium fluoride, calcium tungstate and steadying salts of sodium and potassium; these materials may be uniformly distributed through the electrodes or confined to a central core. Unfortunately the impregnated carbons are expensive and, in open arcs, are rapidly consumed. Long carbons are necessary to secure reasonable burning hours and to lower the net electrical resistance of the carbons, to enhance their mechanical strength and to act as a special steadying core, a metal wire is often placed centrally through the electrodes. The requisite terminal voltage is reduced by the impregnation of the carbons and the arc itself is rendered highly luminous (now supplying 65 per cent. of the total light).

Arc Lamp Regulation.—In order to strike the arc and subsequently to vary its length to suit changing internal and external conditions, most lamps depend upon the joint action of shunt and series solenoids. The details of the mechanism vary considerably, but the principle generally employed is that the carbon holders normally "float" under the control of the shunt and series coils. When the adjustment thus obtainable is no longer sufficient, a clutch permits the carbons to slip together by their own weight, after which the regulating coils again take up the fine adjustment. Fig. 84 shows the essential features of the Excello flame arc, some of the parts being displaced for clearness.

Connections.—Arc lamps may be connected in pure series, pure parallel or parallel series. Pure series connection is economical of line copper and is very popular in America. In this country it is practically obsolete; it requires special high voltage generators and is dangerous to life. Pure parallel operation involves supply at an unreasonably low pressure, but parallel supply of groups of from two to seven lamps in series is satisfactory from every standpoint, and is the usual arrangement in England. When running lamps in "short" series, a ballast resistance or inductance is necessary to secure steady burning, and the loss occurring in this accessory should be taken into account in determining the overall efficiency of the lamp. The use of choking coils instead of line resistance may reduce the specific consumption of flame arcs on alternating current circuits by as much as 30 to 40 per cent. In short series groups, a substitutional resistance or inductance is usually arranged to take the place of a lamp should the latter be incapacitated for any reason. In "long" series groups, the faulty lamp may simply be short circuited, the excess pressure per remaining lamp being insignificant; in such cases, too, no ballast resistance is required, the remaining arcs of the series steadying any arc which is temporarily unstable.

A new type of *two-phase arc lamp* described by Blondel employs two pairs of carbons. The net illumination is practically uniform even on 25 cycle supply. A ratchet mechanism permits a single set of regulating coils to be employed whilst still providing for unequal feeding of the carbons when required. The lamp may be fed from 3 ph. mains through a Scott T-transformer.

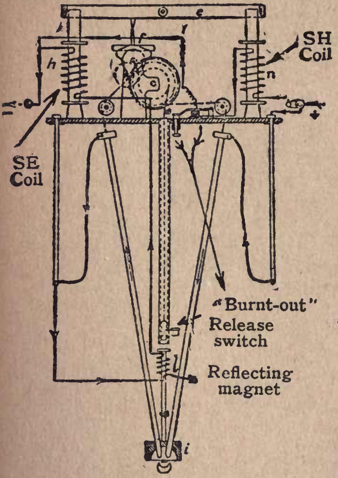


FIG. 84.

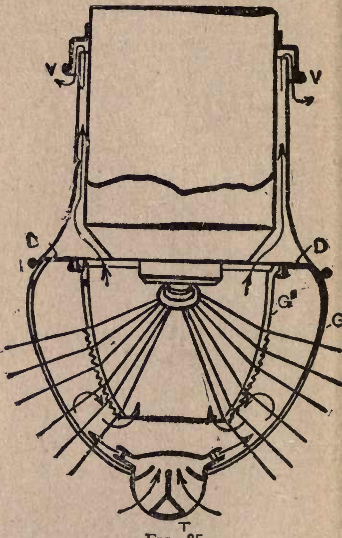


FIG. 85.

Arc Lamp Globes and Fumes.—The density of globe used to enclose an arc varies with the extent to which the latter fluctuates or wanders; and with the service, which determines the steadiness required in the net illumination. The denser the globe, the greater the loss of light by absorption. The fumes from impregnated carbons tend to form opaque deposits on globes, and in some cases the glass is "frosted" by corrosion. Fig. 85 shows the "Excello" arrangement of two globes. Convection currents are established automatically so that fumes never reach the cool outer globe and the inner globe is always too hot to cause condensation. The gases escape as shown, the diaphragm D preventing access of fumes to the lamp mechanism. A special ventilating "corona"

in the Crompton-Blondel lamp (Fig. 89) carries fumes clear of the lamp globe and control coils and mechanism.

The Jandus "regenerative" lamp (Fig. 86) burns impregnated carbons in an air-tight enclosure. Gases from the arc circulate downwards through the side tubes and upwards through the central glass cylinder, the walls of which are swept by a stream of hot gas. Practically the whole of the deposits is in the chamber above the cylinder, whence it is removed easily when recarboning. The carbons are vertical and one pair lasts from 80 to 100 burning hours. The same lamps may be used on either d.c. or a.c., and

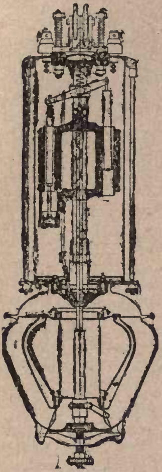


FIG. 86

FIG. 87

FIG. 88.

FIG. 89.

burn in series at 50 to 70 volts per lamp. No fumes can escape from the interior of the lamp, which may therefore be used safely indoors.

The Abbey enclosed flame arc is similar to the Jandus type, but circulating tubes from the bottom and top of the lamp are carried well above the top of the globe and are connected by detachable covers (Fig. 87). This arrangement facilitates cleaning the tubes.

As a result of prolonged experiments in connection with the street lighting of Manchester, the clear inner and opalescent outer flame arc lamp globes, shown dotted in Fig. 88, have been

replaced by globes of the shape shown full. Dioptric globes have a strongly-defined optical centre, hence a slight change in the arc position seriously affects the light distribution; the open bottom of such a globe produces marked dip in the c.p. curve 60–80° below horizontal. Curves A, B, Fig. 88, refer respectively to a 550 w. lamp using the dioptric inner globe, shown by full lines, and (A) a clear outer globe densely frosted up to 48° from the horitonzal; (B) an outer globe with a dense bottom frosting tapering off to clear glass 40° below the horizontal. In the latter case, the lamp provides 3600 c.p. at 23° depression, as compared with 2250 c.p. at 20° depression, using the original (dotted) globe.

Half-Watt Tungsten v. Arc Lamps.—The open type arc lamp burning plain carbons is practically obsolete except for projection work. Gas-filled tungsten lamps can even compete with the carbon arc for cinema and similar projection work if a special arrangement of filament and high-efficiency optical system be employed. The arc lamp is unchallenged for high power projection, *e.g.* searchlights. The "half-watt" lamp has displaced arcs in lighting any but very large interiors. For the latter and for outdoor lighting where high candle-power units are required, the choice between half-watt lamps and flame arcs can be made only by detailed comparison of individual circumstances. For small and medium power lighting units in any application, the gas-filled tungsten lamp is hard to beat. The following values of watts per mean lower hemispherical c.p. assume the use of suitable fittings: *Gas-filled tungsten* 0·55–0·9 w. *D.C. arc, open type, plain carbons:* (*a*) Two in series on 110 v., 0·68–1·0 w. (*b*) Three in series on 110 v., 0·57–0·73 w. *D.C. arc, enclosed, plain carbons:* (*a*) One on 110 v., 0·8–1·1 w. (*b*) Three in series on 220 v., 0·7–0·8 w. *Flame arc, open type, inclined carbons:* D.C., 0·24–0·17 w. A.C., 0·16–0·19 w. *Flame arc, enclosed, vertical carbons:* D.C., 0·2 w. A.C., 0·25–0·3 w.

Searchlights.—Special focus-type tungsten lamps are used for flood lighting and for relatively low power searchlights (for fire brigade service, aeroplanes, etc.), but the carbon arc remains the illuminant for high power service. The Beck lamp uses small carbons worked at high current density (nearly 500 amps. per sq. in.). The outer shell of the carbons is kept relatively cool; the arc is made to burn steadily and centrally; and wasteful burning in air is prevented. U.S. tests show that the maximum illumination from a 44 in. Beck lamp is about 2½ times that from the standard U.S. Navy 60 in. lamp. The range of a searchlight depends primarily on the luminous output of the arc lamp and the design, location and efficiency of the reflector. Atmospheric

absorption operates on light proceeding from the lamp to the objective and on light reflected from the latter to the observer. The net effectiveness of the equipment depends also on the angle subtended by the object and on the colour of it and its background.

ELECTRIC LIGHTING.

The principal measurements of photometry are determination of candle-power; light distribution; illumination of surfaces; colour analysis; and investigating reflecting power of surfaces.

TABLE IV.—PHOTOMETRIC MAGNITUDES, UNITS AND RELATIONSHIPS.

Magnitude.	Symbol.	Unit.	Equation of Definition.
Intensity of Light	I	International Candle	$I = F/\omega$
Luminous Flux	F	Lumen	$F = I.\omega = I.S/r^2 = E.S = \pi.Q$
Illumination	E	Lumens/Sq.cm.	$E = F_i/S = I/r^2$
Radiation	E′	Lux = meter-candle	$E' = F_e/S = \pi.b = m.E$
Brightness	b	Candles/Sq.cm.	$b = I/S.\cos e$
Quantity	Q	Candles	$Q = b.s$
Lighting	L	Lumen-Hours	$L = F.T$

ω = Solid angle through which light is radiated; S = area (sq. cms.); $\pi = 3{\cdot}1416$; e = angle between ray and normal; T = time (hours).

I, b, Q are expressed in candles.
F, E, E′ are expressed in lumens.
L is in lumens or spherical candles.
$E' = \pi.b = m.E$
$F = \pi.Q$

F_i = incident flux
F_e = emergent flux.
m = coefficient of diffuse reflection or transmission.
$(1 - m)$ = coefficient of absorption.

Measurement of Candle-power and Illumination.—The principle employed in these two measurements is identical. Essentially the procedure is as follows:—*To compare candle-power* the lamp examined and a standard lamp are allowed to illuminate, separately and symmetrically, two closely contiguous surfaces of similar optical properties. When the brightness of these surfaces seems equal (attained by variation of d, d_1), $C.P.' = C.P. \times \frac{d_1^2}{d^2}$, ($d, d_1$ = perpendicular distances between sources and comparison surfaces and C.P.′ = required candle-power; the standard candle-power, C.P., being known).

To measure the incident illumination on a given test surface, an adjacent and similar surface is rotated in the illumination from a standard lamp till the intensity of its surface illumination equals that of the test surface. A pointer attached to the movable plane then indicates on an experimentally calibrated scale the desired cdl. ft. or cdl. m. of illumination.

Desirable Illumination.—There is great diversity of opinion as to what constitutes a suitable average illumination in various services, but the figures given in Table V. are typical of good modern practice.

TABLE V.—DESIRABLE AND ACTUAL ILLUMINATIONS.

	Cdl. Ft.
Average Interiors . .	0·7–2·0
Reading	1·5–4·0
Machine Shops . . .	2–5
Commercial Shops . .	2–5
Drawing Offices . . .	3–6
Dark Work	5–10
Tungsten Lighting, wts./sq.ft. floor	
Halls and "general" lighting, where "local" lamps also used	0·2-0·4
General interiors . .	0·5-1·0
Dark or fine work . .	1·0-2·0

	Cdl. Ft.
Mean Street Lighting . .	0·1-2·0
Minm. Ditto (Small Sts.) .	0·08
,, (Medium Sts.) .	0·10
,, (Main Sts.) .	0·20
Diffused Daylight .	10-40
Sunlight in Rooms .	50-100 up to 500
Sunlight in Open .	2000-8000
Moonlight . .	0·015-0·030

In general, uniform illumination of interiors should be aimed for, and in street lighting the ratio of max. to min. illumination should not exceed 4 or 5 : 1, but is sometimes 20 or more : 1.

Intrinsic Brilliancy.—The specific brightness to which the eye is directly exposed should preferably not exceed 0·05–0·10 c.p. per sq. in., though 4 or 5 c.p. per sq. in. is sometimes (wrongly) suggested as a safe limit. To reduce the exposed luminous intensity of various sources, use is made of diffusing globes which, being translucent, become secondary sources of intrinsic brightness lower than that of the primary source in nearly the same ratio that their area is greater. A useful rule for estimating globe diameters is Dia. $= 0{\cdot}56\sqrt{(k.a./p)}$; where $k =$ m.s.c.p. of source; $p =$ desired c.p. per sq. in. of secondary source; and a varies from 0·9 for clear glass to 0·5 for dense opal.

Indirect Lighting has now become very popular for interior lighting. The actual luminous source is entirely hidden from view and throws its light on to a white ceiling or top reflector which then illuminates the room by diffuse reflection. In semi-indirect lighting installations part of the total light is simply diffused by the bowl of the fitting, which is of opal glass or other translucent material. Some semi-indirect fittings are designed

TABLE VI.—AVERAGE INTRINSIC BRILLIANCIES.

C.P. PER SQ. INCH.

Sun . . .	600000	Neon . .	55	Cooper-Hewitt .	17
Carbon Arc Crater (Forrest)	104500	L.P. Gas Mantle	20-35	Moore (nitrogen) .	14
Flame Arc . .	5000			Candle Flame .	3
Nernst Filament .	2000	10in. Frosted Globe, containing Flame Arc			20
Metal Filament .	1000	8in. Opal Globe, containing 16 c.p. Incan.			0·2
Silica Lamp	200-600	Japanese Lantern			0·01
Carbon Filament .	400	Walls, Ceilings, etc. . .			1/10000-1/100
H.P. Gas Mantle .	200				

TABLE VII.—COEFFICIENTS OF ABSORPTION.

	Per cent.		Per cent.
Clear Glass	5-10	Dirt on Prismatic Glass .	15-30
Prismatic	10-20	Enamelled Reflector (fingered)	20
Lightly Obscured . . .	20	,, ,, (greasy)	40-50
Heavily Obscured . .	30-50	Light Yellow Glass . .	15-20
Dirt on Smooth Glass Globe	5-15	Other Light Colours .	20-40
,, Frosted ,,	10-20	Deep Colours	80-95

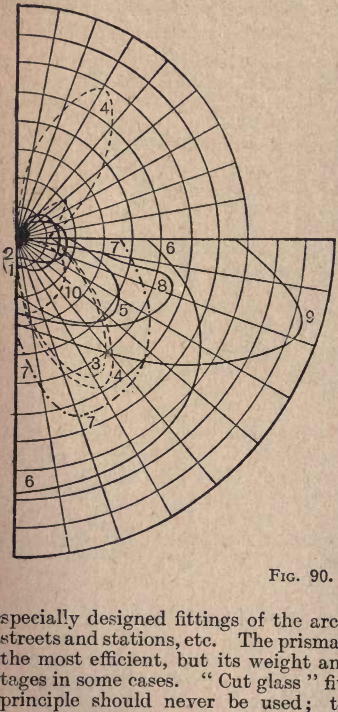
If cleaned every one or two months, reflectors and globes seldom increase in absorption more than 5-10 per cent.

to utilise the holophane principle in conjunction with diffuse reflection and transmission. Wholly indirect lighting is liable to produce " flat " results by the complete elimination of shadows, and it is an interesting fact that a higher mean illumination is generally considered necessary than where direct lighting is employed.

Complaints of unsatisfactory lighting from indirect and semi-direct units are frequently attributable to dirty bulbs and fittings. A hardly perceptible film of dust may reduce the effective light by 20 per cent. and the loss may increase to 50 per cent. after several months of neglect. Semi-direct lighting is little if any dearer than direct lighting using gas-filled tungsten lamps, the total diffusion and absorption losses being about equal in the two cases if suitable fittings be used.

Polar Distribution.—Every type of lamp has a very characteristic polar distribution of candle-power, a detailed examination of which is of the greatest importance in determining the most suitable application of that type and in choosing the most appropriate types of globes and reflectors to adapt it for various services. Typical polar curves for various lamps are collected in Fig. 90. The effect of a.c. supply in increasing the upper hemispherical c.p. of vertical arc lamps should be noted. For street lighting where a maximum amount of light should be projected at

10° to 20° from the horizontal, in order to reduce the diversity factor of the lighting. In the "Excello" lamp the normal polar curve (curve 6, Fig. 90) is corrected for street lighting purposes by the use of "dioptric" prismatic ridges on the exterior of the anti-deposit globe (Fig. 85); the resultant polar distribution is very similar to that of the "Jandus" lamp (curve 9, Fig. 90). Groups of tungsten lamps in special lanterns are now widely used for street lighting. Numbers of half-watt tungsten lamps in



1. Carbon Filaments.
2. Metallic Filaments.
3. D.C. Open Arc.
4. A.C. Open Arc.
5. D.C. Enclosed Arc
6. Open Flame Arc; inclined carbons.
7. Magazine Flame Arc.
8. "Blondel" Axis Flame Arc.
9. "Jandus" Regenerative.
10. Tubular Lamps.

The distribution curve of the Silica lamp is very similar to curve 10; a certain 3600 m.h.s c.p. lamp gave 2000 c.p. at 5° below horz.; 3000 c.p. at 15°; 4000 c.p. at 35°; 4500 c.p. at 55°; 4750 c.p. at 63°; and 5000 c.p. from 75° to 90°.

Fig. 90.

specially designed fittings of the arc lamp type are to be seen in streets and stations, etc. The prismatic type reflector is invariably the most efficient, but its weight and cost are serious disadvantages in some cases. "Cut glass" fittings designed on no definite principle should never be used; they invariably give patchy illumination.

Wherever possible, provision should be made for the harmonious and effective accommodation of electric signs at the time buildings are planned.

TABLE VIII.—COEFFICIENTS OF DIRECT AND DIFFUSE REFLECTION.

	Per cent.		Per cent.
Best Mirrors	80-90	Best White Paper	80-85
Reflecting Prisms	90	White Ceilings	50-70
Speculum Metal	70	Light Yellow Paper	40-60
Steel	60	White Wood	40-50
		Dark Papers	10-20
		Very Dark Papers and Fabrics	1-5

Colour and Choice of Lamps.—It is usually preferable that artificial light should resemble daylight as nearly as possible—particularly if colours have to be matched. For fog and smoke penetration, a yellow or red light is best; violet rays are photographically most actinic; the human eye is most sensitive to yellowish green. The only discernible effect of working under monochromatic illumination (providing this is arranged to avoid glare, etc.), is temporary colour fatigue, *i.e.* temporary inability to match colours by white light. Ultra violet rays are particularly injurious, but are completely screened by ordinary glass. Diffused or indirect lighting by metallic filament lamps is now usual in up-to-date interior illumination. Arc lamps burning selected carbons and fitted with intensive reflectors and special filter glasses are used for colour judging and matching in many dye and paper works, warehouses, etc. For lighting small streets and open spaces, metallic filament clusters can hardly be beaten; for display work and lighting large spaces the yellow flame arc is the most efficient lamp known.

TABLE IX.—COLOUR OF LIGHT EMITTED BY VARIOUS LUMINOUS SOURCES.

Candle—yellow to orange.
Oil Lamp—yellow or pale orange.
Fish Tail Gas Burner—yellow to pale orange.
Incandescent Gas Mantle—white with distinct green tinge.
Acetylene—tolerably white.

Carbon Filament—decidedly yellow.
Metallic Filament—yellowish white.
Nernst—nearly white.

Open Arc—closest approach to daylight.
Enclosed Arc—excess of blue and violet.
Flame Arc—yellow, red or pinkish white, according to impregnation.

Cooper-Hewitt Mercury Arc—blue-green; no red.
Silica Mercury Arc—violet-blue to yellow-green.
Moore Lamp—rosy yellow with nitrogen; good approach to daylight with carbon-dioxide.
Neon—red; no blue rays; gives rich rose light if used with metal lamps.

Manchester street lighting tests (March 1913) showed *inter alia* that 49 high pressure gas and 44 flame arcs per mile, hung at 26½ and 27½ ft., providing respectively 1750 and 2970 m.h.s. c.p., and 0·39 and 0·5 min. horz. ft. cdls., cost per mile per annum, £617 and £254 respectively.

Electric Lamps for Photographic Purposes.—The Eastman research laboratory recommendations may be thus summarised. *Portraiture.*—Diffused source required; either low intrinsic brilliancy *or* a large diffusing screen *or* a combination of these methods. Gas-filled tungsten lamps, mercury vapour lamps or flame arcs may be used. *Photo-engraving.*—One flame arc on each side of the copy board is a good arrangement. In making half tone prints on metal, use a small but powerful source as far away as possible, thus keeping sharp definition of the dots. *For printing* use enclosed or flame arcs for silver papers; mercury vapour lamp for platinum papers; enclosed or mercury arc for blue prints. *Cinematograph Work.*—Mercury vapour (glass or quartz type) and flame arcs are used; a good arrangement is mercury lamps on adjustable frames above and to one side of stage and arcs in front.

Workshop Lighting.—*Natural Lighting.*—High-angle illumination is specially valuable; shops on the "bay" system with "saw-tooth" roofing glazed on the *flatter* slopes gives the best results. *Artificial Lighting.*—75 per cent. of accidents in factories occur after 4 p.m., and the monthly average is 50–100 per cent. higher in winter than in summer. A medium, uniform "general" illumination (say 2–4 cdl. ft.) should be augmented by "local" lamps over special tools, etc. (to bring the total illumination there up to 5–10 cdl. ft.). Conflicting shadows and dazzling of one man by another's lamps must be avoided. Excessive intensity is as dangerous as insufficient lighting, and sharp contrasts in illumination are very fatiguing; naked lamps should not be used. *All globes and reflectors should be cleaned at regular intervals*—varying from one to six weeks. Walls should be whitewashed and machine frames, etc., painted green or slate-grey.

Useful approximate rules for general workshop lighting by distributed tungsten lamps are :—*Mounting Height:* 8 to 14 ft. for 48 to 80 c.p.; 16 to 20 ft. for 80 to 200 c.p.; 20 to 24 ft. for 200 to 450 c.p. lamps. *Spacing* (*along and across*): equal to mounting height till latter exceeds 10 ft.; from 0·5 to 1·0 times mounting height when latter is between 12 and 25 ft.

EARTHING.

The object of "earthing" or "ground-connection" is to use the earth as part of an electric circuit (as in telegraphy) or to maintain a certain conductor, network or piece of apparatus at as nearly as possible earth potential under all circumstances. A conductor is taken from the part to be "earthed" to a metal conductor buried in the ground, but the best form of earth plate and interconnector varies with circumstances. The earth is deliberately used as a "return" conductor only for weak current circuits; if it be used for heavy current return, part of the current seeks pipe lines and other buried metalwork and leads to electrolytic damage. In traction work, where rail return is employed, it is necessary to bond all joints and (possibly) use a negative booster to prevent current wandering and causing electrolysis. Usually earth plates are :—(1) To "earth" neutral conductors of generating and distributing schemes. (2) To earth metal which is normally "dead" but which might become "live" by accident (*e. g.* switchboard frames, switch cases, cable boxes, motor frames, guard wires, etc.). (3) To provide a metallic path to earth where direct leakage to earth and consequent electrolytic trouble would otherwise arise. (4) To furnish a discharge path for lighting or other high pressure current from an arrester in a distributing circuit; from a lightning conductor; or from metal transmission line poles. (5) To take advantage of earth capacity in wireless telegraphy. In any case the two essential parts of the equipment are the over-ground earth connection and the earth plate itself.

Earthing the "Neutral." In favour of earthing the neutral conductor of generating and distributing systems is : Limitation of pressure between line and earth (to ½ "outer" pressure in 3 wire d.c. and to 58% line pressure in 3 phase a.c. systems). Against earthing are : Impossibility of operating with an earth fault on one line (this is, however, an advantage in mining service); the stress on insulation and risk of flash to frame or casing is permanent (though less than it is *at times* in an unearthed system); risk of shock or explosion by temporary contact between earth and line. Safety to life, by reduced intensity of shock, is only appreciably increased in case of low pressure circuits. Earthing reduces risk of fatal shock from l.t. circuit due to contact with h.t. system. Security of service, limited strain on insulation and (sometimes) cheapened insulation are factors determining earthing in h.t. systems. Limited p.d. and possibility of immediately detecting and isolating an earth-fault are chief arguments for earthing neutral; where it may be practicable and desirable to be able to operate temporarily with such a fault, the neutral must not be earthed. Resistance (or inductance for a.c.) should be placed in the earth connection to limit current

flowing to earth fault; pressure of the neutral is then raised above earth by amount depending on impedance and current. To prevent circulating currents (especially triple frequency) between generators in parallel, with earthed neutrals: (1) Place choke coil between each neutral and earth bus *or* (2) Place few ohms between bus and earth, switch one generator on to bus and others through small spark gaps to bus.

Connecting to Earth Plate.—In interiors the connection to "earth" (generally water pipes) may be by a wire, preferably insulated and erected and treated with the same respect as the live wires; section say No. 6 S.W.G. minimum; and not less than neutral wire when grounding 3 wire d.c. *or* than phase conductor when grounding 3 phase a.c. systems. If a lead or zinc covered iron wire be used, its section should be twice that of the equivalent Cu wire. In power stations, etc., an earthing bus may be provided on the switchboard; a copper ring main connecting condensers, feed and circulating water pumps, etc., gives good earthing in many cases. Strip conductor preferable to round for earth connection from h.t. circuits; run should be short and direct as possible. Special devices (shunted gaps, powder resistances, etc.) are used to permit easy h.t. discharge whilst quickly interrupting "power" discharge. Connection to actual earth plate (or pipes, etc.) should be of ample surface and definitely established by bolting, screwing or sweating, etc.; also, protected from mechanical damage, corrosion or inadvertent removal.

Earthing conductor for multi-core cables should (when used) be integral with cable; if armouring of insufficient capacity (*i. e.* less than 50% that of line conductors enclosed) may utilise copper sheath or provide special internal earthing core. Earthed guard wire over transmission lines forms partial screen against electrostatic disturbance; may be utilised as grounded neutral; or as earthing bus for guard screens, metal towers, etc.; or (if below line wires) to carry pilot wire cable by slings. Single wire protects zone 45° to 60° beneath it; more wires protect wider zone; may be of stranded galvanised steel; barbed wire more effective against some forms of atmospheric electricity.

Forms of Earth Plates.—*Water pipes* are satisfactory if extensive; proportionate in size to the current they may have to carry; and well jointed mechanically. *Gas pipes* should not be used; arcing at joints might cause fire. *Steel frames* of buildings have usually insufficient earth contact to be reliable; it is unwise to pass current deliberately into reinforcement of concrete structures; on the contrary such reinforcement may well be earthed to reduce risk of electrolytic corrosion. *Copper plates* buried in coke in moist place is common and satisfactory arrangement; desirable to carry coke down 8 ft. or so; charcoal, being free from sulphur, is less favourable to corrosion. *Copper*

strip may be used in form of star or large spiral. Tinned copper is less corrodible. *Galvanised steel pipes* (with driving cap and cast steel shoe if necessary), driven 8 or 10 ft. deep and connected in parallel, give low resistance and good current distribution; pipe diameter 1 to 3 inches but not important electrically.

Earth Plates for Wireless Telegraphy.—Must be widespread; constant and low resistance necessary for quantitative investigations and maximum efficiency. Water pipes often satisfactory but should not extend above apparatus; gas pipes unsuitable; copper plates or (better) copper strip " star " in coke common in small power stations; copper strip in trench, terminating in plate in coke, is useful form. Wire netting on rocks washed by sea may be useful at coast station; otherwise, radial wires carried to iron pipes driven vertically or zinc plates set edgewise (on circle of diameter comparable with aerial height and say 50-100 ft. as minimum); if necessary, wires may be continued radially to another ring of plates. Wires need only be laid few inches below turf. Plates in brook, pond or swamp; spikes; or copper netting pegged down are useful for portable stations. In all cases the earth lead should be as short as possible and run straight down from coupling transformer (not parallel to aerial lead).

Earth Resistance.—Varies with nature and moistness of soil; with area of earth plate (but not in simple proportion); and with path of flow of current. At first resistance between two earth plates increases with distance apart; then decreases greatly owing to larger effective section of current path. Resistance of earth much less to high frequency current than to d.c. or ordinary a.c. Chief resistance near plates where current density necessarily greatest. A number of plates offer less resistance, better distribution and more security of permanent satisfaction than a single plate of equal area; the individual plates should be 5 to 15 ft. apart. *To test resistance,* pass a.c. (to eliminate polarisation) through earth plate and out at second similar plate or water pipe system. Break exists if no current flows: otherwise $R = E/A$ = resistance of two earth plates in series *or* of single " earth " if water pipe return used (resistance of latter generally negligible). Watering earth plate with brine (or placing salt seepage-box above it) reduces resistance but favours electrolytic corrosion. D.C. flow if at all sustained produces electrolytic damage and may cause osmotic drying. Earthed parts should be in parallel, *never* in series; no fuse or switch in earth connection. Metal which might attract earth currents must be bonded where necessary and definitely earthed: all earth plates bonded in parallel. Test and inspect earth connections periodically; add fresh plates when resistance appreciably increased, unless due to defective connection or abnormal dryness, in which case rectify or water.

ELECTRIC BELLS AND BELL CIRCUITS.

An electric bell is an electromagnetic appliance used extensively for purposes of signalling, and is an instructive example of the intermittent action of electromagnets. As is well known, an

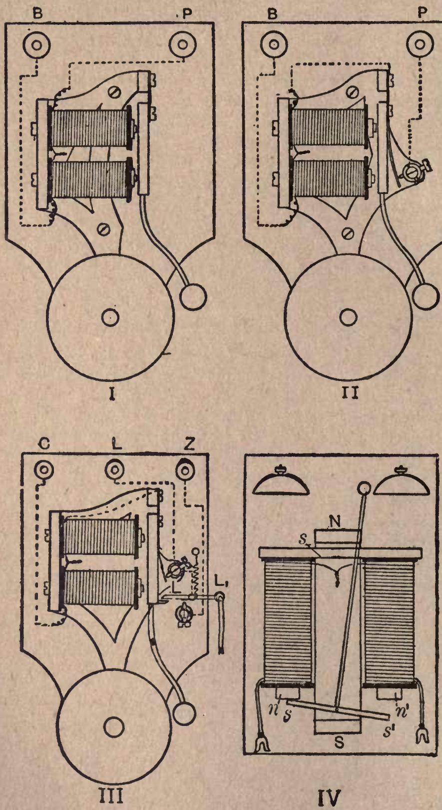


FIG. 91.

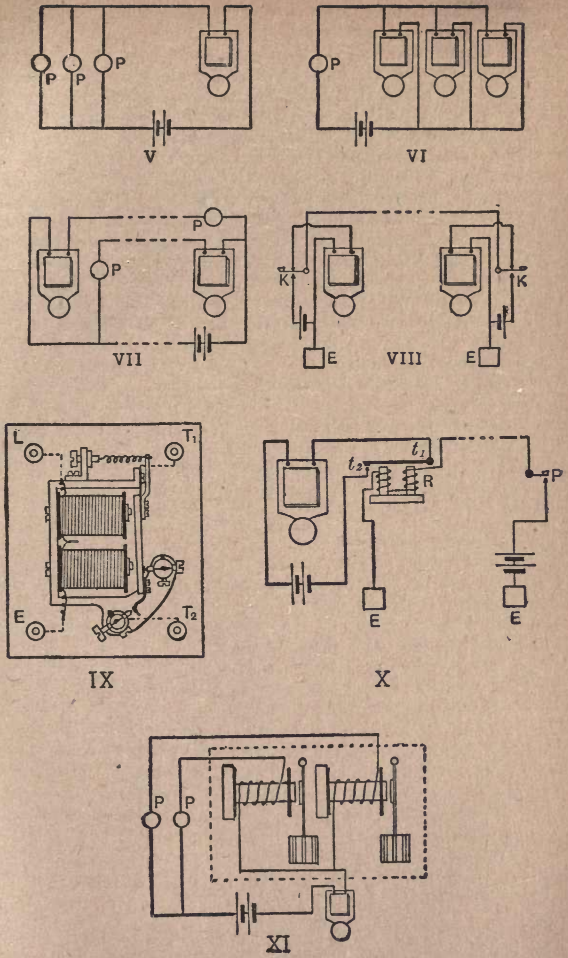


FIG. 92.

electromagnet with soft iron core responds instantly to the make and break of the current traversing the windings. There are four types of electric bells: (*a*) the *single-stroke* (Fig. 91 I.), in which there is one stroke each time the circuit is closed; (*b*) the *ordinary* bell (Fig. 91 II.), in which vibratory motion of the hammer results so long as the circuit is closed by means of the push; (*c*) the *continuous-ringing* bell (Fig. 91 III.), in which the bell continues to operate after once the circuit has been closed, until the lever L L is raised and made to engage with the catch in the armature; and (*d*) the *magneto* bell (Fig. 91 IV.), which is made to operate by means of alternating currents supplied by a magneto generator; the hammer is attached to the armature ss^1, in which the middle point is magnetised as a north pole (and the extremities s and s^1 as south poles) by the south pole S of the permanent magnet N S, whilst the north pole N magnetises the ends of the core of the electromagnet as north poles n and n^1, and when an alternating current is made to traverse the coils of the electromagnets, the poles n and n^1 will be alternately strengthened, thus giving rise to alternate attractions on the ends of the armature ss^1, and alternate strokes on the two gongs. This type of bell is used in telephony. In Figs. 91 I. and II., B denotes the terminal to be connected to the battery of Leclanché cells, and P the terminal to be connected to the push; in Fig. 91 III. the terminals C, L and Z have to be connected to the carbon (of battery), the line and zinc of battery respectively. (See Bell Transformers.)

Bell Circuits.—Referring to Fig. 92, the connections shown are those for:—V. Ringing one bell from several pushes. VI. Ringing several bells (in parallel) from one push. VII. Ringing a bell at either station from a push at the other (using one battery). VIII. Ringing a bell at a distant station, using a battery at each station and one line wire with earth return. IX. A relay closing a local bell circuit and operating on a line current much weaker than that required to ring an ordinary bell. T_1, T_2 are the local, and L, E the main circuit terminals: the complete circuit is shown in Fig. 92 X. The connections for an indicator, showing which of a number of pushes has been used to ring a common bell, are represented in Fig. 92 XI. In cases where bells are mounted side by side and operated from different rooms or departments, widely differing tones can be secured (without installing a heterogeneous collection of different shapes and sizes of gongs) by making radial saw-cuts inwards from the rim of the standard gong selected. By varying the number and length of the cuts very distinctive tones can be secured.

Wiring.—Bell-work is simple, but it is not—as appears often to be imagined—beneath contempt. Good materials and good workmanship are essential. Double cotton-covered, paraffined,

rubber insulated wires of No. 20 S.W.G. are recommended for standard bell-work. In very large buildings a low voltage No. 18 lighting-conductor should be used for the main battery lead. As far as possible, distinctive colours should be used in the line wires from various rooms. Enamelled wire is very convenient, particularly where inconspicuous surface wiring is required; five or six enamelled wires can be stranded to form a neat cord. In jointing, remove enamel; do not nick wire; solder the joint and paint with quick-drying insulating compound. In all cases, avoid kinks. Concealed wiring should be in moisture-proof conduit.

Pushes.—Select those with stout bases, strong contact springs, and plenty of room for good contacts to be made without risk of short circuit. Spring contacts should be faced with metal (preferably platinum) not subject to oxidation. A wide variety of pushes and door and window contacts (for shop and burglar alarms),

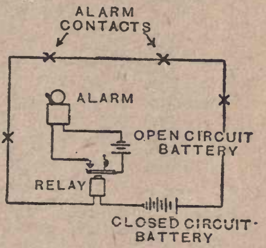


FIG. 93.

thermal switches (for fire alarm circuits), and time switches are now on the market, but it is impossible to describe these in the space here available. The circumstances of each case will determine what general type of contact maker is required; all that is necessary is to ascertain that the fitting does, and will continue in service to do, what is expected from it.

Burglar Alarms are essentially call-bell circuits arranged with special care, as regards concealment of wiring, and operated by special contacts in windows, doors, or show-cases, or under carpets, etc. The alarm may be given when a normally open circuit is closed, or when a normally closed circuit is broken. The latter arrangement is best but more costly, since current flows continuously in the alarm circuit. Gravity Daniell cells are very suitable for closed circuit work, but, owing to the injurious diffusion of the electrolyte which occurs on open circuit, auxiliary switches must be provided if it is desired to open windows, etc., during the daytime without causing the alarm to ring. The most reliable system is the combined closed-open-circuit represented in Fig. 93.

TELEPHONES.

Receivers and Transmitters.—The original telephonic instrument was the Bell transmitter and receiver (sketched in Fig. 94). In essentially the same form, this instrument is used at the present day, though now only as a receiver. An ebonite or wooden tube T contains a long horse-shoe magnet N S fitted with soft iron pole pieces on which are mounted coils C. The diaphragm D is of ferrotype, and, vibrating under the air waves set up by speech, alters the permeability of the magnetic circuit of N S, and hence the flux threading C C. There are thus induced synchronous e.m.f.'s which, being applied to the line circuit, cause sympathetic diaphragm vibrations and hence speech reproduction at the

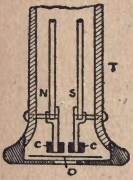


FIG. 94.

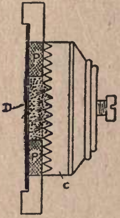


FIG. 95.

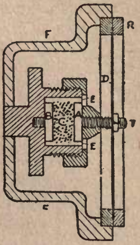


FIG. 96.

remote station. The only source of energy in the voice and the efficiency of the various energy transformations being 0·01%, it is obvious that the Bell instrument can only be used as a transmitter over very short distances. All receivers now in use consist of one or other form of microphonic or loose contact; the latter is traversed by a suitable current and, the contact pressure being varied by speech vibrations, the microphone acts as a relay controlling a comparatively powerful line current. Almost without exception, the microphone contacts are of carbon, but the rod and plates first employed have given place to various types using one carbon block and a number of granules. The *Deckert Hunning* transmitter, shown in Fig. 95, comprises a carbon disc C on the front of which are formed a number of square pyramids (the function of which is to keep the granules from packing). The diaphragm is a thin carbon plate (varnished to exclude moisture). An annular ring P of cotton wool leaves only the centre of D free to vibrate and avoids the presence of a shunt of idle granules in parallel with the central pellules. The ring P also damps out the natural vibrations of the diaphragm. The central pyramids are

tipped with silk (attached to their truncated tops) to aid in preventing packing and to damp the diaphragm. The *Solid Back* transmitter (Fig. 96) comprises an iron or aluminium diaphragm D mounted between rubber rings and connected by the bolt C to a carbon " piston " A, between which and a fixed block B are carbon granules C. The granule chamber is covered by a mica plate E. This microphone is very sensitive and does not pack seriously.

Induction Coil.—In order that the current variations, on which speech reproduction depends, may be a maximum, it is clearly necessary that the resistance in the microphone circuit must be as low as possible. For this reason the microphone is not connected directly in the line circuit but is connected to the primary of the induction coil or transformer P S (Fig. 97). The primary current variation being now considerable, the secondary (line) current variations are correspondingly great.

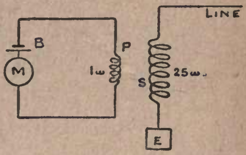


FIG. 97.

Connections.—*Wall Set.*—The connections for an ordinary wall set, with separate battery at each station, are shown in Fig. 98.

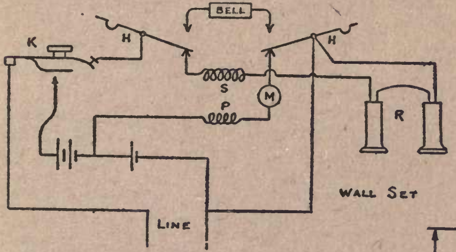


FIG. 98.

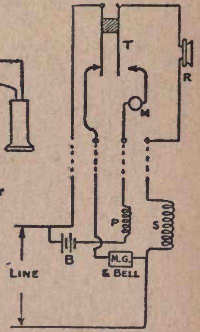


FIG. 99.

When not in use the receivers hang on H H and thus connect the call-bell to the line. The microphone needs one cell; ringing requires three cells. The secondary S being in the receiving circuit, the speaker hears his own message.

Table Set (Fig. 99).—A magneto generator and a.c. bells are used for ringing purposes; the generator is short circuited except when the driving handle is rotated. The speaking switch

contacts T are brought together and on to the microphone contact either by a grip lever in the microphone and receiver frame or by the rising of a spring cradle in which the latter rests when not in use.

Exchanges. — *Requirements and Operations.* — Instant and certain indication of subscriber's call; operator "answers" and ascertains number required; operator tests required line to determine whether it is "engaged"; if it is not, she "calls" the second subscriber and connects his line to that of the first. The operator must be able to listen to the conversation for control purposes, and hanging up of the subscriber's instrument must be

FIG. 100.

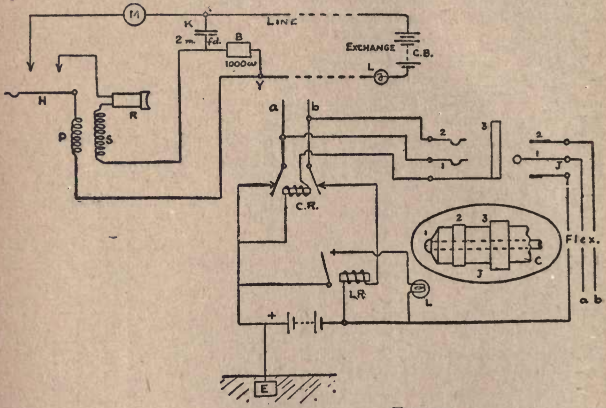


FIG. 101.

at once indicated on the exchange board, so that the "through" connection may be removed and the two lines left clear.

Switchboards.—This consists of a number of vertical panels with horizontal "jack" shelves in front. On the lower part of each vertical panel are say 100 call lamps and plug sockets corresponding to the subscribers which this particular operator has to answer. On the upper part of the panel are sockets for calling and through connecting to the whole of the subscribers connected to the exchange.

Central Batteries.—All new exchanges are provided with duplicate 24 volt accumulator batteries to avoid the cost of installing and maintaining individual subscribers' batteries. The discharge rate of the central batteries may be 500 or 600 amps. or more. The central battery is always earthed on the positive side.

For calling purposes, 20 cycles a.c. is provided by a 50v. alternator in the exchange.

Subscriber's Set.—This comprises a microphone, receiver, and magneto bell (Fig. 100). To call the exchange, the subscriber simply lifts his receiver off H. The condenser K prevents direct current flowing from X to Y, and the high induction of the bell prevents high frequency speech current from following this path.

Exchange Connections.—The act of raising the subscriber's receiver closes the circuit in which is the line relay L R (Fig. 101). The operation of the latter lights the lamp L which has a long bulb of small diameter, and which is seen end-on through a hole in the switchboard immediately below the jack-hole corresponding to the subscriber concerned. The construction of the plug J

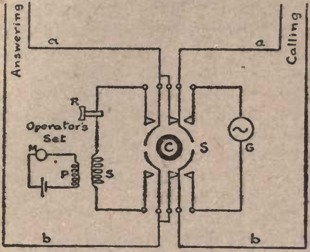


FIG. 102.

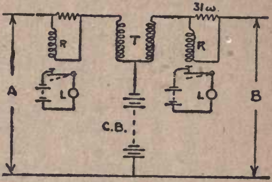


FIG. 103.

is shown inset in Fig. 101; three contacts, 1, 2, 3, fixed on an ebonite core C complete the connections shown when the jack is inserted. On the horizontal panel of the board are two rows of jacks and one row of switches. One of the back row of jacks is used to answer the calling subscriber, and one from the front row is then plugged in the socket corresponding to the subscriber required. The answering jack connects A, B (Fig. 101) to the operator's set and extinguishes the lamp by the cut-off relay C R. A click or intermittent buzzing is heard when the calling jack is placed in a thimble connected to a line already engaged. The switch connections are shown in Fig. 102. The ring C represents the switch thimble. By pressing this to the left the operator connects her head-piece to the calling subscriber. She then presses C to the right (altering the spring connection in a manner which will be obvious from a study of the sketch), tests for "engaged," and, if the line is clear, calls the second subscriber. C being released, the subscribers are connected "through." By pressing C to the left, the operator places her instrument in parallel with the line and can hear without interrupting the conversation.

Calling Off.—Referring to Fig. 103 during the time speech is

proceeding, a high frequency speech current is superposed on the central battery currents, and is transferred from the one line circuit A to the other B by the transformer T. Relays R R are connected in the line circuit, so that directly the line current is broken (by hanging up the subscriber's receiver) the lamp L is lighted or extinguished as the case may be.

It will be understood that the connection diagrams here presented are diagrammatic and fractional, *i.e.*, only the fundamental part under discussion is represented in each, for the sake of simplicity.

ELECTRICITY ON SHIPBOARD.

Current Supply.—Direct current supply is used invariably on shipboard. Admiralty work is now mostly at 220 volts; three-wire, 220 volts distribution is practised in some new liners, but 110 volts is the most common pressure. At one time reciprocating engines were always used to drive ship dynamos, but turbines are employed in modern vessels and Diesel engines have been tried in isolated cases. On liners, the generators installed differ little from standard central station type; on battleships and cruisers, open-type 200–250 kws., 225 volts, 6–12 pole interpole machines are used; and on torpedo boats semi-enclosed machines of smaller kw. capacity are employed. To ensure maximum security of supply, several generators in parallel feed ring mains or independent generators and circuits may be arranged

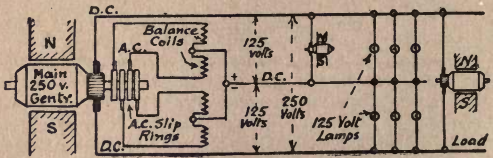


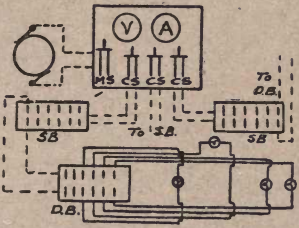
FIG. 104.

where continuity of supply is the primary and cost a secondary consideration.

Distribution.—Three-wire distribution in low voltage d.c. systems offers important copper economy and provides double the lighting pressure for power supply. Self-contained three-wire balanced generators were introduced many years ago; the distinctive feature of such machines is the provision of auto-transformers or "balance" coils connected to armature slip rings as in Fig. 104. In the case illustrated, three-phase four-wire connection is made to the balance coils, the centre points of which are interconnected to form a neutral point for connection of the middle wire of the distribution system. The balance coils comprise

single windings on a laminated iron core; the losses in them are negligible. Commutating poles ensure sparkless commutation under all loads; to secure good voltage regulation the machine may be compounded by series coils connected half in the positive and half in the negative outer. The space required by such a three-wire generator is little greater than that occupied by a standard two-wire generator of equal output. Three-wire generators (any number of poles and speed) operate in parallel with each other or two-wire machines as simply as two-wire machines; there is no need to consider the frequencies of the balance coil currents or to synchronise the latter.

The single-wire ship-return system of distribution is sometimes employed but it is inadmissible within 30 ft. of compasses. The double-wire distribution box system illustrated in Fig. 105 is preferable. The number and description of circuits vary with the size and class of vessel concerned and the routes on which she



MS = Main Switch. CS = Circuit Switch. SB = Section Box. DB = Distribution Box. ⊕ = Lamps

FIG. 105.

sails. A large tramp steamer will usually have forward, saloon and midships, aft, engine-room, and cargo cluster circuits, to which a projector circuit will be added if the boat is to pass regularly through the Suez, Panama or other ship canals. A liner may have service, night, passenger, heating, fan, ventilation, cargo, machinery, winch and crane circuits.

Cables.—Cables and wires for marine use must be so constructed as to resist rough usage, moisture and sea water. Minimum size 1/18 S.W.G. (1/20 S.W.G. for bells). Usual sizes 1/18, 1/16, 1/14, 3/20, 7/20, 7/18, 7/16, 7/14, 19/16 and upwards. For exposed situations (machinery spaces between decks and cargo spaces, exposed deck lights, etc.) lead-sheathed, steel-armoured rubber cables should be used. For inside work similar cable without armouring and tapping may be used. Lead cables, jute-covered and armoured by fine steel wires, are used in the German and some

other navies. All cables must be carried through suitable glands in bulkheads and in iron piping through decks.

Switchgear and Fittings.—In interior parts of liners, standard land type switchgear and fittings are quite suitable; the latter are of the most luxurious and ornamental type in saloons and cabins of modern liners. In exposed situations and all "working" parts of the ship, switchgear and fittings must be waterproof, strong and strictly utilitarian. Casings must be ironclad with rubber gaskets and watertight glands, etc.; lamps must be protected by thick glass globes. Very special switchgear is required on warships to provide the necessary degree of reliability. Automatic gear (*e. g.* overload and no-volt circuit-breaker releases) must be sensitive to the conditions determining its operation and yet be unaffected by the tremendous concussion of the gun firing (a broadside from a modern battleship causes the deck to rise and fall 2 in. or so).

Lighting.—The lighting of cabins and saloons requires no special treatment and the only special feature in the lighting of engine-rooms, holds and decks, etc., is the strong and weatherproof nature of the fittings employed. It is hardly necessary to point out that metal lamps should be used wherever possible, current economy being particularly important by reason of the low distributing pressure frequently employed. *Navigation Lights.*—Two masthead, two side and one stern light are generally fed from a special distribution box. In the event of a lamp failing, visible and audible alarms are given in the chartroom, a spare filament meanwhile preventing total extinction of the light. *Searchlights.*—Instead of running these through ballast resistances from constant voltage mains, electrically driven constant current generators may be connected directly to the searchlights, steady burning being secured automatically by the characteristics of the constant current dynamo. The Admiralty motor-generator set is built with vertical shaft; to provide over 100 volts on open circuits; and 110 amps. at 65 volts on load. A shunt regulator for voltage control places resistance in the motor shunt as it removes it from the generator shunt field and thus maintains constant r.p.m.

Fans.—Powerful electrically driven fans now replace the ventilating cowls which were formerly so prominent a part of the top hamper of every vessel. Better ventilation is obtained than is possible by use of cowls. Small cabin and porthole fans can be plugged on to lighting mains, but blowers and exhaust fans (such as required when large volumes of air have to be moved or appreciable resistance has to be overcome) should be connected to power mains. All fans are generally direct coupled to their driving motors and the latter are arranged for more or less wide and fine speed regulation according to requirements. Sometimes one motor is sandwiched between two fans. Electric motors

are now available which will withstand the dust and heat of boiler-rooms. In a certain case, the engine-room fan delivers 24,000 cub. ft. air per minute and the ventilating fan 3000 cub. ft. per minute; control by d.p. switch, fuses and tramway type controller. Electrically driven fans may be used in conjunction with the refrigerating system. On modern battleships there are from 80 to 120 electrically driven fans ranging from 7½ in. to 36 in. diameter. The largest fans are used in the engine-room and deliver a minimum of 30,000 cub. ft. per minute. Speed control by series parallel connection of the field coils or by use of a few thick-wire and many thin-wire ampere-turns, from the latter of which current is diverted to secure speed control.

Winches, Windlasses and Capstans.—Boat Winches are generally worm geared. One compact design casts the gearcase and the controller-case in one with the lower and upper halves respectively of the magnet frame. Two warping drums are fitted; average duty, 1 ton at 150 ft. per min. *Cargo Winches.*—For small cargo there is a worm-geared type of winch with two warps. The motor and controller, etc., are protected by a sheet-iron cover with inspection doors. Control is by a single hand wheel, magnetic braking being provided. Average duty, 30 cwts. at 100–120 ft. per min. For heavier work, a two-speed spur-geared winch is usual. Two warp ends, a drum and two independent sets of spur gearing are fitted. Duty 5–2½ tons at 30–60 ft. per min. *Windlasses* similar to steam type but with motor in place of steam-engine driving the cable lifters through spur gearing. Warp ends sometimes fitted to lift the shaft. *Capstans.*—Generally used to provide 3 to 5 tons rope pull when warping. May be of overdeck type, in which all gearing is in capstan head; or of underdeck type, a shaft being led to the capstan from the motor and gearing on the lower deck. Typical warship equipment is one 30 H.P. capstan aft and one 140 H.P. or two 70 H.P. machines forward driving 3 or 4 separate heads through clutch and gearing. The "flapper" brake is used extensively to hold capstans; the brake block is of wood, nearly semicircular and carried by a pivoted lever at the other end of which is a faced cast-iron block. The latter is attracted to the motor yoke by magnetic leakage (when the motor is switched in circuit) thus releasing the brake blocks against the control of powerful springs. Unlike band brakes, this type grips and releases smoothly and does not require frequent adjustment.

Lifts.—Lifts are now fitted on all large liners and warships; the electric type is more complicated but also more reliable, efficient and lighter than the hydraulic type. On all except short travel stores lifts, safety gear must be fitted to the balance weight as well as to the cage. Bulkhead doors have been abandoned in modern war vessels, hence it is necessary to go well above the water line to get from compartment to compartment. For

the use of the wounded men and officers and for elevating ashes, electric lifts with cages $2 \times 2 \times 7$ ft. are provided. Push-button control is fitted and the latest lifts are underdriven so that they can rise through the upper deck. From 8 to 10 *coal hoists* are provided on battleships and cruisers. Average duty is to raise 1 ton at 200 ft. per min. and lower at not more than 425 ft. per min. A compound wound motor may be used with the shunt designed to limit speed to twice normal on no load; on lowering, the reversed series field swamps the shunt field, hence a centrifugal braking governor is required. For slow hoisting speeds (taking up slack and easing off) an armature diverter is employed; at higher speeds main series resistance is cut out; full speed is obtained by diverting some of the series coil current. *Boat hoists* are equipped similarly and controlled by a master controller. Special *ammunition hoists* are provided on all warships; endless chain system to big guns; double bollard hoists to lighter weapons. Duty, lift 300 lb. at 120 ft. per min.

Rudder and Turret Control.—A number of systems have been devised for the remote electrical control of ships' rudders, turrets, etc. Reliability and simplicity are essential; relays and other delicate devices are taboo. It is easy electrically to reproduce the ship and rudder motions in the captain's cabin or elsewhere. Sometimes series motors but generally compound machines are used for electric steering; a.c. motors are unsuitable. In the Hele Shaw-Martineau electric steering-gear, the rudder is set by hydraulic rams working on either side of the rudder stock and fed with oil from an electrically driven rotary variable stroke pump. The pump motor is controlled by the steering-wheel, and should the rudder be deflected by shock, the pump is started automatically and returns the rudder to the position corresponding to that of the steering-wheel. The manipulation of gun turrets is an exceptionally difficult service owing to the great weights concerned, the heavy shocks to be resisted and the prime importance of absolute reliability. Speed range of 60 : 1 is obtained efficiently by using the Ward-Leonard system with variable generator field. The Admiralty have reverted to hydraulic turret gear on some of the latest cruisers.

Telephones. — Very complete telephone installations with central battery exchanges are provided on liners and war vessels. On liners passengers can communicate by telephone with stewards, other passengers and local and trunk land lines when in port. For navigating purposes, special weatherproof, loud-speaking instruments are installed on bridges, forecastle and crow's nest; in engine-, boiler- and chart-rooms and in turrets and control stations on war vessels. Exchange boards are similar to those on land; spring clips and gimbals on cabin sets prevent the

receiver being jerked off its hook and prevent the latter from opening due to rolling of the ship.

Wireless Telegraphy has repeatedly proved its value in saving life at sea. Every liner now carries a powerful equipment and publishes a daily bulletin of news thus received. Current is obtained from a special generator set or through a rotary converter from the ship's mains. In emergency, operation is from a storage battery. Usually the aerial equipment comprises one main antenna for long and one for short wave lengths and an entirely independent emergency aerial. A $1\frac{1}{2}$ kw. Marconi set has effective sending range of 70 to 300 miles by day and two or three times as far by night.

ELECTRICITY IN COAL MINES.

Direct Current *versus* Alternating Current.—*D.C.* possesses the advantages of simple circuits and switchgear and high efficiency, is safer to life (owing to lower pressures used), involves minimum capital cost and requires two conductors instead of three. D.C. motors start well on heavy loads. *A.C.* secures the well-known advantages of high tension transmission and static transformation; A.C. motors have no commutators, but require a heavy current when starting on load; resonance causes trouble in some cases. On the whole, D.C. is to be preferred for low powers and A.C. for high powers.

Voltage, etc.—"Low" pressure is 250 v. or less; "medium" is 250 to 650 v.; "high" is 650 to 3000; "extra high" exceeds 3000 v. For motors under 50 H.P., 250–600 v. is suitable; above 50 H.P. 2000–3000 v., A.C. is economical. Where A.C. is employed, 25 cycles, three-phase is convenient.

Generators and Motors.—*Reliability*, mechanical strength, high overload capacity and efficiency are essential. The generators, being surface machines, are practically standard types. Motors having to work underground must be liberally rated on account of the poor cooling facilities and must in the majority of cases be perfectly enclosed (preferably with long tortuous cooling paths for the gases generated by possible explosions within the casing). Motors must be damp-proof; have minimum number of parts and liberal clearances; easily accessible for repair; liberally designed bearings abundantly lubricated. See that windings are thoroughly impregnated and oil throwers on shaft effective.

Series Motors are used for pumps, haulage locomotives, etc.; their high starting torque is valuable, but there must be no risk of the load coming off.

Shunt Motors are used for main and tail haulage, being kept running and used in conjunction with a friction clutch. If applied to coal cutters the cutter can be "cleared" without racing.

Compound Motors are largely used; they do not race on light load and yet vary their speed to suit heavy loads.

Squirrel-cage Motors are the simplest type available; their complete freedom from sliding contacts is valuable in mining work. These machines are simple, strong, and have high efficiency and reasonably high power factor.

Wound Rotor Motors necessarily replace squirrel-cage machines on most loads of over 10 H.P., owing to their higher starting torque; they are, however, liable to sparking.

Cables.—Almost any good make is suitable if liberally insulated and mechanically armoured; lead sheathing is watertight, corrosion proof, and provides the requisite "earthed" sheath. Impregnated whipcord, tarred rope or leather covering is tough and flexible and prevents a fault at one point giving shocks elsewhere *viâ* the metal sheathing. Flexible suspension of the cables by leather slings minimises risk of damage by "falls" or chance blows.

Main Cables. — Impregnated paper, lead-sheathed steel-armoured cables are usual, but a recent suggestion is to use high tension aluminium cables in mine shafts, dispensing with armouring and using steel ropes for return current. The latter expedient uses old winding ropes advantageously and is cheaper than armouring.

Temporary and "Trailing" Cables.—Flexible cores; two or three main conductors and one earth core of 50 per cent. carrying capacity and at least 0·022 sq. in. section. Rubber insulation; vulcanised bitumen and multiple braiding or cab tyre sheathing (*see* Cables). Sometimes leather case is sewn on. These cables *must* be inspected daily and tested to four times working pressure when new and after any repair. Plugs not making contact till completely enclosed and then making earth contact first, must be used for all temporary connections. *Metal Conduits* reduce the flexibility and so increase the risk of damage of the system: water is liable to lodge in the conduits. One advantage of enclosing all single core cables belonging to one circuit in an iron pipe is that automatic switchgear acts before open arcing occurs.

Switchgear must be specially stout and reliable; all live parts cased in, all breaks oil immersed or completely enclosed; most H.T. switchgear is suitable for mining use without radical alteration.

Liquid Starters, if carefully designed and enclosed, are safe for use up to 700 volts and 1000 H.P.; they are cheaper than other types for heavy motors.

Resistances.—These should be enclosed no more than is essential to prevent mechanical injury: they should be placed vertically on walls or posts to enable ready cooling: soldered joints should be avoided and, if possible, oil immersion, and embedding in sand.

cement or enamel: porcelain insulation best. In machine cutter rheostats, braided resistance wire may be wound on mica insulated brass tubes. All parts to be freely accessible. A resistance made up of alternate plates of iron and carbon is satisfactory for heavy duties and may be run near red heat without injury.

Fuses of cartridge type: circuit breakers set for $2\frac{1}{2} \times$ normal current.

Leakage Current from cable system must be recorded twice daily, and is limited to $\frac{1}{1000}$th maximum current supplied.

Ventilation.—Owing to the permanence of this load it is highly desirable that the fans should be electrically driven, so improving the net load factor of the colliery. The large fans (30–40 ft. dia.) favoured by early practice and typified by the Guibal fans would require a large, slow and costly motor, whereas the much more efficient high-speed centrifugal force or suction fan (6–7 ft. dia.) is suitable for direct coupling to a lighter and cheaper high-speed motor. It may be several years before a mine is so far opened as to require the full air delivery for which its fan was installed. During this period electrically-driven fans should be run at reduced speed without rheostatic loss. Cascade or variable pole operation of three-phase induction motors is efficient, and the inflexibility of the speed control provided is relatively unimportant in this case. The original cascade system (which is best where only a few definite speeds are required) utilises energy from the rotor of the main motor in an auxiliary induction motor, which aids its output and that of the main machine. Modifications providing uniform speed control and high p.f. use a commutator auxiliary machine and yield "slip energy" (1) directly-mechanically (Kramer) or electrically (Heyland); (2) indirectly by three-phase d.c. converter on main motor shaft (Linsenmann Kramer); (3) through motor generator to supply network (Scherbius).

Pumping.—From 20,000 to 200,000 galls. water run into many mines daily, thus producing a duty of high load factor; if the pumps have not to run continuously they should operate during the night-shift, their effect on the load factor of the station being then specially valuable.

Reciprocating Pumps are the most flexible and are the best for high suction heads: the three-throw ram type is commonly employed and has an efficiency of 90 per cent., which is well maintained at all heads and speeds. The pump runs at 30–50 R.P.M. and hence requires double speed reduction if electrically driven: much of the higher efficiency otherwise available is thus sacrificed.

Rotary Pumps of the centrifugal or turbine types are cheaper, and the small space they occupy fits them for shaft-sinking work, etc.: such pumps may be direct coupled to electric motors, so compensating for the otherwise low pump efficiency (75 %): rotary pumps are inflexible and repairs are costly.

Coal Cutters.—The three main types of these machines (*see* below) are all capable of electrical operation, but mechanical and electrical considerations have to be sacrificed somewhat to the stringent space requirements. Though there is no limit to the length of the machines (within reason) their height is seldom over 2ft. and in some cases is only 16in. Long working hours on heavy duty, abundance of dust and chips and unskilled manipulation combine to make the service a difficult one : systematic working, enhanced safety and increased output at less cost are the benefits accruing to machine mining. Electrical operation is more flexible and efficient than compressed air working : various tests have shown that electrical driving requires from 35–60 % the power (*in the engine house*) required by compressed air cutters on the same service. From 3 to 3½ % of the total stoppages of a certain electrically-driven cutter were due to electrical defects : the cost of repairs varied from 5s. per 1000 to 5s. per 10,000 tons undercut.

The *energy consumed* varies from 0·33 to 0·70 B.T.U. per sq. yard of undercut, according as the "holing band" is soft coal or hard fireclay.

Bar Coal Cutters can be driven from electric motors through a 2 : 1 gear reduction, whereas *disc* and *chain* machines require 30 to 60 : 1 reduction. The bar machine is on the whole the most reliable and the most suited to electrical driving : the starting torque required is very low. The *load factor* of coal cutters is very poor, and it would be ridiculous to confine the electrification of a mine to these machines.

Coal Cutter Motors must be completely enclosed and of very low build : *D.C. patterns* are of high efficiency and start on heavy loads without excessive current. They are usually of the Manchester type : four-pole machines with carbon brushes : the enclosing shell forms part of the magnetic circuit and is therefore of high permeability cast steel : the slotted armature is mounted on a cast-iron hub extended to carry the commutator independently of the shaft.

A.C. patterns may be three-phase squirrel-cage machines : cast steel slotted stator core : laminated rotor built on cast-iron core : copper end rings cast round the projecting ends of the rotor bars. An auto starter should be used, sufficiently large to obviate oil immersion. Slip-ring motors provide higher starting torque; stators generally in "star."

Controller of the barrel type capable of operation from either end of cutter. Renewable contacts and fingers and magnetic blow out coils should be fitted. Keep switch contacts in good condition.

The motor also propels the cutter along the winding face by means of a rope drum and anchor post (200 ft. rope usually carried).

Horse-Power.—Standard coal cutters require 10–20 H.P. (including propulsion): sometimes one motor only, sometimes two with series parallel control: "headers" and "shearers" for short faces and vertical cutting respectively feed 1–2 ft. per min. and require 15 H.P.

Conveyors aid the rapid and cheap clearing of the coal "face" with a minimum handling of the coal (each handling causes 3 to 5% breakage). An 8–10 H.P. motor at 500–600 R.P.M. handles 30 tons per hour.

Haulage.—Electrical haulage (along main "roads" or "galleries") is more flexible and economical than steam or pony haulage: three-phase motors are less suitable than D.C. motors, owing to their non-slowing on heavy loads: 500 R.P.M. at the motor with double speed reduction to 30 R.P.M. at the haulage drum is usual: employing a heavy slow speed motor (200 R.P.M.) single gearing suffices. Usual haulage speeds—4 to 8 M.P.H.

Horse-Power.—For "main and tail" haulage, 150 to 200 H.P. motor; for "endless-rope" system, say, 30 to 40 H.P.

The Cost of main and tail haulage (electric drive) was in a certain case 1 B.T.U. per ton hauled: working at 25 to 30 tons per journey and twenty journeys per day = 500 to 600 tons per day. The *Load Factor* is very bad, being of the order of 5%.

Electric Winding.—The chief advantages of electric winding are: oil, waste, and maintenance 25–33% less than for steam plant; economical operation during years before full output is required; reduced cost of winding house and pit-head gear; higher winding speeds (particularly for men); flexible, efficient and safe working more easily secured. Short-period tests are useless in comparing electric and steam winding. Taking twenty-four hours' results over considerable periods, the total cost of electric winding compares favourably with that of steam.

Alternating current is most suitable for electrical winding machinery; the main motor is of about 1000 H.P. normal rating, the peak demand being from 2000-3000 H.P. Most of the peak is supplied by the flywheel storage set, this equalising of the load being its whole function.

Electric Drills.—Compressed air is very suitable for percussive drills, such as are used in hard holings, especially as the cooling and ventilating effected are valuable: rotary drills (soft holings) are certainly best driven electrically. A 1–2 H.P. electric motor is adaptable to both types, and is flexible and economical. A totally enclosed 400-500 volt motor, delivering 400–500 blows per minute, will drill $1\frac{3}{4}$–2 in. holes 5 ft. deep at the rate of 1 ft. per min. in rock or 5 ft. per min. in coal. Machine drilling costs about one-third as much as hand drilling, thus saving 1d. to 2d. per ton output. The weight of the electrical equipment is 100–200 lb., the total weight of the whole drill being 300–500 lb. A specially powerful (4 H.P.) motor, however, brings the total weight up to about 1000 lb.

Shot Firing may be on the low tension or "glow" system, or on the high tension or "spark" system; the incandescent wire or glow system is generally considered the safer. A magneto exploder, though heavier and costlier than a battery of small primary or secondary cells, is more convenient, reliable and durable. The magneto armature is hand driven through gearing at 2000-3000 R.P.M. at the moment of closing (automatically) the firing circuit key. For glow firing the magneto output is 3 amps. and 20 volts: for spark firing, 12) volts and negligible current; an allowance of 20–30 volts per fuse is made when a number are fired in series. Series connection ensures that no part is fired unless all the fuses are in order.

Telephones.—Telephonic communication is now legally enforced between the generating station and pit-head and between each of these and the pit-bottom and pit-distributing centres. The telephones used are watertight and must be extraordinarily strong to withstand the usage to which they are subjected. Special sets are supplied by mining electrical manufacturers. Lightning protectors (say of the carbon gap in vacuo type) must be fitted to the telephone circuits.

Signalling Circuits.—For these are required strong signalling keys, liberal section of conductors, large plate batteries (so as to secure high current capacity) and *regular inspection and attention.* No. 1 Leclanché cells are suitable and the maximum permissible voltage in any signalling circuit is 25 volts. No open sparking system is now permitted in haulage ways, and combined visual and audible signals are required in the winding engine room. The electro-mechanical system of haulage road signalling retains the convenience of the continuous bare wire electric system (in which signals are given simply by gripping the wires together) without introducing the risk of open sparking. The electro-mechanical equipment comprises totally enclosed pull switches mounted at 100 yds. intervals and connected by draw wires. An electro-mechanical system of shaft signalling can be applied to existing rapper systems to comply with the new Rules at minimum expense or a purely electric signalling system can be installed. In either case, the signal given is indicated visually to the winding engineman till the signal is obeyed; the usual bell and hooter signals are given in addition. Arrangements are made to prevent mixing of signals; the source of each signal is indicated and the signals are returned automatically to the sender so that he may at once detect mistakes or defects.

Lighting.—Carbon and metal lamps are used to light the main "roads" in a number of mines. At the working face Davy lamps still predominate (a recent report shows 4300 electric and 720,000 oil safety lamps to be in use), but portable electric lamps have given great satisfaction wherever they have been installed,

and their use is rapidly extending and may conceivably become compulsory. The higher illumination provided reduces nystagmus and increases the speed and safety of working. Lightness, strength and economy and long lighting hours are desiderata. No open sparking must be possible, designs must be approved. Wooden cases are light, strong and tough, but bulky and difficult to fix securely to lanterns. Metal cases are apt to be dented. Aluminium alloy castings with cast-in attachments and bushes are very satisfactory. Lamp should be supported resiliently and protected by thick annealed glass cover; it must be extinguished automatically if the latter is broken and before the lamp bulb is broken. This may be secured by spring, contact pin or compressed air. Screw type switch finds most favour. Battery generally a lead storage cell; must be light, small, non-gassing, non-spillable and durable; if removable, should be easy fit and protected from shock. Nickel-alkali cells offer important advantages in respect of lightness and life. The difficulty in recharging is to allow for varying states of discharge. H.O. Regulations require at least 1 spher. c.p. after 9 hrs. continuous burning; test for this at end of shift. The Ceag lamp won the 1912 H.O. prize for a 2 c.p., 10 hr. electric safety lamp complying with certain stipulations. A corrugated pressed steel casing protects the celluloid container of a simple and strong type of lead accumulator, and can only be unlocked by aid of a strong magnet. A 1·5 c.p. 2 v. tungsten lamp is used within a thick glass dome; should the latter be broken, spiral springs holding the lamp are broken and the circuit is opened. Weight complete, 4 lb.; charging occupies four or five hrs.; lamp burns continuously for sixteen hrs. The objection that electric lamps give no indication of fire-damp has been overcome by the introduction of various fire-damp detectors. The Stach lamp has an auxiliary electrically lighted Davy lamp for gas detection and estimation. The Manley lamp utilises the catalytic action of a platinum salt to detect the presence of as little as 0·25% gas.

COMPARATIVE WEIGHT OF LEADS FOR DIFFERENT SYSTEMS OF POWER DISTRIBUTION.

The following table compares the weight of leads for equal power, drop and voltage for different systems of distribution:—

For single-phase two wires	100
,, single-phase three wires (assuming the third wire half the section of the others)	31·22
,, two-phase four wires	100
,, two-phase three wires (reckoning the voltage between lines and common return)	72·8
,, three-phase three wires (mesh)	75
,, three-phase four wires (neutral wire from common junction)	29·2

SMALL ELECTRIC TOOLS.

SMALL tools complete with an electric motor (or driven through flexible shafting by an electric motor), are light and compact, and of high productive capacity. The flexibility of control and the overload capacity of the electric motor are valuable characteristics, and, compared with compressed air tools, electrically-driven tools are smaller, simpler to maintain and more convenient to use; only a flexible cable, plug connector and switch are required, compared with flexible air piping (generally more or less leaky) and an air compressor. An important advantage of small tools is that they perform light operations in odd places more quickly and conveniently and with higher efficiency than a large machine tool. There are innumerable instances in which it is more economical to use a small portable drill or a tool driven through small flexible shafting, than it is to take the job to a fixed machine (which is probably much more powerful than required) and there set up the work as though a long operation were to be performed. Small power and portable tool requirements are met excellently by small electric motors, and in the present notes special attention is paid to equipments of fractional horse-power. The intelligent use of such equipments is capable of reducing manual labour on the one hand, and the wasteful use of more powerful machinery on the other.

Constructional Features.—Whatever the tool concerned, the reliability of the motor and the driving mechanism is the primary consideration. A high speed motor is generally employed for the sake of lightness and compactness, machine-cut gearing being used to drive the working spindle at the desired speed. The location of the working spindle with regard to the motor and gear-casing should be such that the work can be reached in any desired position; for instance, a drill with the spindle offset can be used closer into a deep angle than can a drill which is in line with the motor spindle.

Mechanical and Electrical Features of Small Motors.—These features may be discussed in some detail, because the satisfactory performance of any electrically driven small tool depends essentially upon the motor employed. Unquestionably the best materials should be used throughout in the interests of reliability, efficiency and lightness. Thin laminations of the best available magnetic iron reduce the core losses to a minimum, thus improving the efficiency and simplifying the problem of ventilation. For a similar reason, the armature resistance should be as low as possible. The lower the magnetic and electrical losses, the less the heating of the insulation, and hence

the less the deterioration of the latter. A fan on the rotor contributes materially to the ventilation of the machine. Friction losses may absorb a serious proportion of the power developed by a motor of fractional horse-power, and although plain phosphor-bronze bearings with grease or oil-wick lubrication are satisfactory, it is generally preferable to employ ball bearings. Ring lubricated plain bearings may be used in machines of over $\frac{1}{4}$ or $\frac{1}{2}$ H.P. The fact that ball bearings do not wear appreciably is of great assistance in maintaining alignment and in maintaining concentrically the very short air gap of induction motors. The overall length of the motor is reduced materially by the use of ball bearings, and if the latter be packed properly with grease, they are dust-proof.

Reliability and efficiency being secured, it is important that the motor be as light and compact as possible; that it have a good, neat finish; and that little maintenance or attention be required. Liberal rating is very desirable so that the motor has a reasonable overload capacity and does not overheat on normal load. A protected or totally enclosed construction is usual, and there is advantage, in point of good appearance, light weight and strength, in the use of a drawn steel frame in preference to cast iron. Easy mounting or attachment of the motor is an important consideration, and such speed control as is provided should be simple and definite. Other desirable features are accessibility of components; good balance and quiet running; substantial terminals which, together with the connections, should be clearly distinguished as regards polarity or phase. Since a relatively small defect will overload a motor of fractional horse-power, a shear pin, friction clutch or belt drive is a useful protective feature; in most cases, equivalent protection may be obtained more simply by the use of a suitable fuse. A gear drive has the advantage of definite speed ratio; where a belt is preferred, Vee-groove pulleys are generally used on motors up to $\frac{1}{8}$ H.P. Suitable pulley and belt sizes are: Up to $\frac{1}{50}$ H.P., $\frac{5}{8}$ in. diam. V-pulley with $\frac{7}{32}$ in. belt; $\frac{1}{50}$ to $\frac{1}{8}$ H.P., $1\frac{1}{4}$ in. to 2 in. diam. V-pulley with $\frac{3}{16}$ in. to $\frac{5}{16}$ in. belt, $\frac{1}{6}$ H.P. to $\frac{1}{2}$ H.P., flat pulley from $2\frac{1}{2}$ in. to $4\frac{1}{2}$ in. diam. with $1\frac{1}{2}$ in. to $2\frac{1}{2}$ in. belt. Oil-immersed worm gearing is used extensively with small motors for speed ratios from 10 : 1 to 100 : 1.

It is important that the magnetic system of the motor be built up from thin laminations of best magnetic iron securely fastened together by insulated rivets or bolts. The laminations should not be short-circuited by reaming the bolt holes or filing the slots. It pays to use first-class insulation between turns of the windings and between winding and core; and all windings should be held securely in place by slot wedges, binding wires or fibre clamps. The insulation used should be unaffected by overheating, which

is liable to be severe in small-tool service. Skewed slots assist in securing uniform torque and quiet operation. A good mechanical and electrical joint is obtainable between the rotor bars and end rings of squirrel cage machines by welding, by riveting and soldering, or by casting solid. Oil throwers or grooves should be used to prevent oil from getting on to windings. Good commutation with fixed brush position is essential to satisfactory performance. The quality of the commutator bars and mica is equally important and can be determined by inspection after the motor has been in service for some time.

Self-lubricating brushes, impregnated with any greasy or oily material, are very liable to pick up dirt, thus increasing the wear and imperilling insulation.

Motor Dimensions, Characteristics and Supply Conditions.—Table I. shows approximately the overall dimensions and space occupied by fractional horse-power motors for 110 v. or 220 v., d.c. or a.c. supply, and speeds ranging from 1000 to 3000 R.P.M. These data form a useful guide, but reference should be made to manufacturers' catalogues when it is important to know the precise dimensions of a machine.

TABLE I.—APPROXIMATE OVERALL DIMENSIONS OF FRACTIONAL HORSE-POWER MOTORS.

Horse-power.	1000 revs. per min.		1500–2000 revs. per min.		3000 revs. per min.	
	Cub. In. (approx.).	Overall dimensions (approx.). In.	Cub. In. (approx.).	Overall dimensions (approx.). In.	Cub. In. (approx.).	Overall dimensions (approx.). In.
1/200	60	5 × 3½ × 3½	37	4 × 3 × 3	30	3⅜ × 3 × 3
1/100	80	6½ × 3½ × 3½	55	4½ × 3½ × 3½	37	4 × 3 × 3
1/70	100	6¼ × 4 × 4	72	6 × 3½ × 3½	55	4½ × 3½ × 3½
1/50	130	6 × 4¾ × 4¾	100	6¼ × 4 × 4	70	5¾ × 3½ × 3½
1/30	180	8 × 4¾ × 4¾	150	6⅝ × 4¾ × 4¾	110	7 × 4 × 4
1/20	235	7¾ × 5½ × 5½	200	8 × 5 × 5	150	6⅝ × 4¾ × 4¾
1/15	275	9 × 5½ × 5½	255	8½ × 5½ × 5½	185	7⅜ × 5 × 5
1/10	330	7¾ × 6½ × 6½	300	9½ × 5½ × 5½	230	9¼ × 5 × 5
1/8	370	8¾ × 6½ × 6½	330	7¾ × 6½ × 6½	250	8¼ × 5½ × 5½
1/6	440	7¾ × 7½ × 7½	400	9½ × 6½ × 6½	320	10½ × 5½ × 5½
1/4	600	10¾ × 7½ × 7½	560	10 × 7½ × 7½	440	10½ × 6½ × 6½
1/3	720	12¾ × 7½ × 7½	660	11¾ × 7½ × 7½	540	9⅝ × 7½ × 7½
1/2	1050	13 × 9 × 9	1000	12¼ × 9 × 9	840	13 × 8 × 8

The weights of these motors vary with the type and make to a greater extent than do the dimensions. A $\frac{1}{100}$ H.P. motor for 2400 R.P.M. weighs about 2 lb.; a $\frac{1}{10}$ H.P. motor for between 1000 and 2500 R.P.M. weighs anything from 25 to 15 lb.; and a $\frac{1}{2}$ H.P. motor for speeds between 1000 and 1500 R.P.M. weighs from 120 to 60 lb. For use in conjunction with farm-lighting sets there is advantage in standardising 32 volt d.c. motors, shunt wound up to $\frac{1}{2}$ H.P. and compound wound from $\frac{1}{8}$ to $\frac{3}{4}$ H.P.

Small motors with series windings are used where the friction load or other non-removable load is sufficient to prevent racing; shunt motors are used for constant speed service; and compound motors are used where the high starting torque and drooping speed characteristic imparted by the series winding are desirable without liability to racing. The complication of a compound

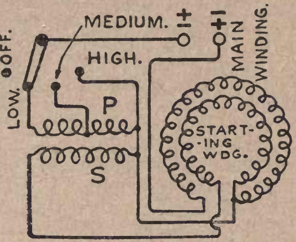


FIG. 106.

winding is hardly justified in motors of less than $\frac{1}{8}$ H.P. Fractional horse-power motors for a.c. supply are almost invariably single phase machines and may be series wound or of the split phase induction type. In the British Thomson Houston split-phase induction motor ($\frac{1}{50}$ to $\frac{1}{2}$ H.P.) the primary winding is in the rotor slots, whilst the secondary is a squirrel cage winding in the stator. The starting winding (which is cut out by a centrifugal switch, when the motor is up to speed) is at first in parallel with the main winding and carries a current which is considerably out of phase with the main current, and therefore produces a rotating field during the starting period. Fig. 106 shows the electrical circuits of the Westinghouse single-phase induction motor for fans, etc. This machine yields a good starting torque and 50 % range in speed (say 1000 to 1500 R.P.M.). The primary P of a transformer with variable primary tappings is connected in series with the main winding of the motor and the secondary is in series with the starting winding which, in this machine, remains in circuit during normal running as well. There is a

large phase displacement between the currents in the main and starting windings, and the motor actually operates as a two-phase machine.

Small motors are often abused by being operated on incorrect voltage or, in the case of a.c. machines, on incorrect frequency. A d.c. motor should run satisfactorily within $\pm$ 10 % of normal voltage, but the possible output is reduced by lowering the voltage. A single-phase a.c. induction motor loses nearly 20 % in output if the voltage be 10 % low, so that it by no means follows that a 220 v. motor is "good enough" for a 200 v. circuit. For a.c. motors the percentage variation in voltage or frequency (or the sum of the variations in each) should not exceed 5 %.

Typical Small Tools.—Probably the electrically-driven tool which is most commonly employed is the *electric drill*, which is available in all sizes from ⅛ in. to 1¼ in. drilling capacity. A tool comprising a ⅙ H.P. motor and capable of drilling up to ¼ in. diam. in steel, weighs about 6½ lb., and can be held and operated by one hand. The motor usually runs at 2000–3000 R.P.M. and drives the spindle at reduced speed through grease-packed gearings. Good graphite grease should be used. Change-speed gears may be fitted if required. Series or compound wound motors yield high starting torque and decreasing speed with increasing load. A tool with 1 or 1½ H.P. motor, capable of drilling 1¼ in. diam. in steel, weighs about ½ cwt. and is provided with cross-handle grips and a breast-plate or a feed-screw for applying pressure to the drill. The data given in Table II are typical.

TABLE II.—ELECTRIC DRILLS.

Drilling Capacity.		Spindle Speed.	Consumption.	Weight.
Steel.	Wood.			
In.	In.	Revs. per. min.	Watts.	Lb.
3/16	5/16	1200–1600	120–180	6
5/16	7/16	700–1000	150–250	10
½	⅞	400–600	200–400	15–20
⅝	1	300–450	250–500	20–25
¾	1½	250–350	400–600	25–35
⅞	1¾	200–300	500–800	30–40
1	2	200–300	600–1000	30–45
1½	3	100–200	1000–2000	45–70
2	4	100–200	1500–3000	75–100

Motor-driven drills of the portable type may be bolted to pedestals for bench service or incorporated with a portable radial drill stand with complete adjustments; or a motor of from ⅛ to ½ H.P. may

be mounted on the pedestal and geared to the spindle of a vertical bench-drill. Small motors mounted on two-wheel trucks are used to countersink holes in ship plates.

A *circular saw* direct coupled to a $\frac{1}{2}$ H.P. motor, which is so mounted that it can be tilted to cut any desired angle with regard to the table, is a useful tool capable of dealing with hard wood up to 2 in. thick. A ball-bearing thrust is provided.

Grinders of all types may be driven very conveniently by electric motors. Portable sets can be taken to the work and wheels driven through flexible shafting are frequently useful in cleaning castings and in reaching places otherwise inaccessible. For internal grinding on small diameters, spindle speeds from 10,000 to 50,000 R.P.M. may be obtained by belt driving from a small high-speed motor. Where the use of a special precision grinder is not justified, excellent results may be obtained by a tool-post equipment comprising a motor on a pivoted frame and a grinding spindle mounted rigidly in ball bearings. An electrically-driven grinder can be used as an independent portable or fixed unit, or it can be fitted to any machine tool and provided with all the requisite adjustments. Table III gives typical data; the weight varies considerably with the fittings provided on the motor frame: a.c. motors frequently operate at lower speed than the equivalent d.c. machine, and in such cases a harder grade of wheel should be used. A useful accessory in this category is a motor combined with an automatic reversing gear, which oscillates a valve-grinding spindle forwards and backwards.

TABLE III.—ELECTRIC GRINDERS.

Emery Wheel.	Revs. per min.	Horse-power.	Weight.
In.			Lb.
$4 \times \frac{3}{4}$	4000	$\frac{1}{4}$	15–25
$6 \times \frac{3}{4}$	3500	$\frac{3}{8}$	20–30
6×1	3000		
$8 \times \frac{3}{4}$	2600	$\frac{1}{2}$	35–45
8×1	2500	$\frac{5}{8}$	
10×1	2000	$\frac{3}{4}$–1	50–65
12×1	1600	$1\frac{1}{2}$	65–85
14×1	1400	2	90–110

Small motors with suitable sockets or chucks are now used extensively to screw down nuts, and to drive wood screws, screwed rail spikes, etc. In small vertical drills and many other machine tools, a small motor may be substituted for the driving pulley otherwise required; the motor occupies little, if any, more room than the belt pulley, and the reduced vibration and belt pull are

frequently an important advantage. Motors of $\frac{1}{6}$ or $\frac{1}{4}$ H.P. may be used in conjunction with farm lighting sets for such purposes as driving churns, cream separators, milking machines, grindstones, horse-clippers, and so on. Larger motors should not be operated from the lighting battery. *Electric fans* are the commonest domestic application of the electric motor, but it is rare to find full use made of a fan in the following applications: Providing a cool breeze in summer or blowing air against hot water radiators in water (thus effecting an important saving in fuel); drying clothes, photo prints, timber, fruit, vegetables, etc., or humidifying air by blowing it over wet wick; removing smoke or odours from kitchens, etc.; preventing steaming or frosting of shop windows; operating advertising devices, streamers, windmills, etc. A convenient tool for blowing dust out of generator windings, etc., consists of a motor-driven fan weighing about 15 lb. complete and delivering a blast of air at 6 oz. pressure through a $1\frac{1}{4}$ in. diam. nozzle.

A useful equipment for *undercutting commutator-micas* consists of a small motor and transmission shaft driving a small circular saw through worm gearing. The complete equipment weighs about 10 lb., and since it is used endways-on and is guided by a steel strip running behind the saw in the undercut slot, the tool can be used without special preparation or dismantling of the brush-gear.

A d.c. or a.c. motor consuming about 50 watts is suitable for driving a *sewing machine.* Supply may be taken from a lamp socket, and the motor runs usually at 1500–2000 R.P.M. Speed control may be by series resistance, but a more efficient method is to run the motor at full speed continuously and to use the foot treadle to release the brake on the hand-wheel and to move an idle pulley so as to tighten more or less the driving-belt. The loss due to belt slip is less than that in the control resistance otherwise needed, and the machine picks up speed more quickly in the former case. Amongst *miscellaneous applications* may be mentioned: (1) Small motors driving tube-scaling tools through flexible shafting. (2) Motors winding watches in repair shops where hundreds of watches per day have to be wound. (3) Motor driven scissors, the motor being mounted between the handle and the fixed lower blade, and driving the upper blade through an eccentric and coupling rod. The blade makes 150 strokes per second and moves only $\frac{1}{16}$ in. at the cutting edge. (4) Motors of $\frac{1}{16}$ to $\frac{1}{3}$ H.P., 2000 to 4500 R.P.M., with rheostat control, used to drive dental drills and grinding wheels, etc., through flexible shafting. (5) A motor of $\frac{1}{4}$ to 1 H.P. mounted on a wheeled trolley, and fitted with a 3-step pulley driving a countershaft which is also carried by the trolley, forms a useful set for miscellaneous low-power driving through belt or flexible shaft.

(6) A motor of fractional horse-power arranged to be coupled quickly to a washing machine, knife-cleaner or other domestic appliances which are not used sufficiently to justifv independent motors.

ELECTRIC WELDING.

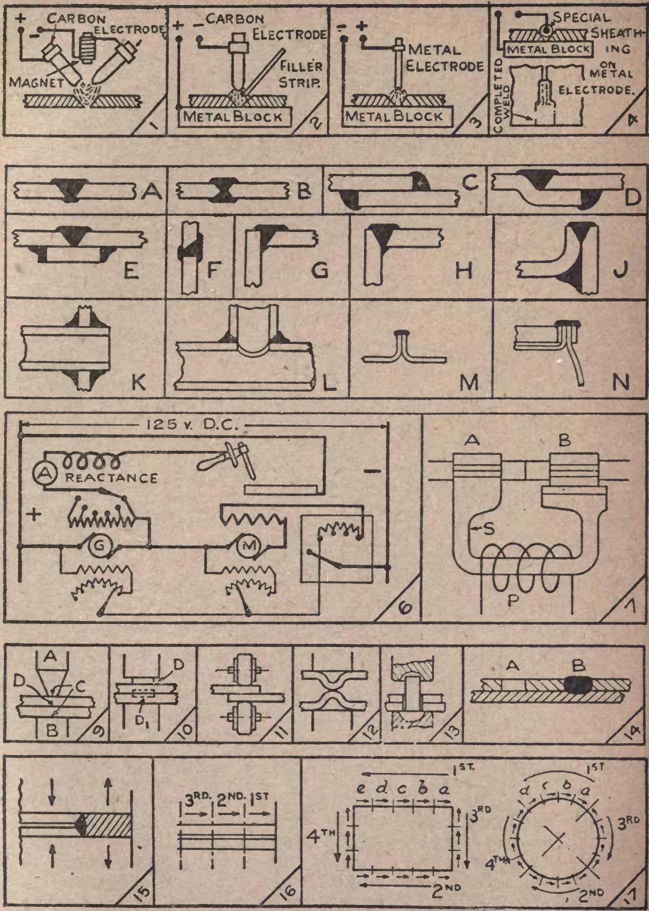
There is employed in electric welding, the heating effect of the electric current as developed either by an arc using carbon or metal electrodes or by current flowing through the contact resistance between the parts to be welded. Whereas *arc welding* melts the parts together (make-up metal being added to the joint if required), and thus produces a cast structure which may be toughened by hammering whilst hot, *resistance welding* (which includes butt, spot and seam welding) consists in heating the parts to welding temperature and then forcing them together mechanically, the whole process being analogous to forge welding. Resistance welding requires the use of a machine which is more or less automatic in action but arc welding is essentially a craft demanding and giving scope for skill and experience on the part of the workman.

Arc Welding Processes.—The arc may be struck between two electrodes carried by a framework and handle, the degree of heating being then controlled by moving the arc towards or away from the work. Alternatively, the arc may be struck between one electrode and the work itself. The *Zerener* process Fig. 107 (1) uses two carbon electrodes at right angles, with an electromagnet to deflect the arc downwards. The *Voltex* system uses a similar arrangement of impregnated carbons but without a deflecting magnet; it is claimed that the metallic oxide used as impregnating material reduces the risk of getting carbon into the weld and provides a long arc which can be used safely to weld or braze thin sheets. The *Coffin* system uses an arc between a carbon rod and a concentric outer carbon tube, diffusion of heat being obtained by electromagnetic rotation of the arc round the annular gap between the electrodes. The *Benardos* system Fig. 107 (2) uses a single carbon electrode, the work being connected to the *positive* terminal of the circuit; were the polarity reversed, carbon would be carried into the weld, making it brittle. A filler rod of soft iron or mild steel is used if metal is required to fill the joint. In the *Slavianoff* process, Fig. 107 (3), one iron electrode is used and the work itself is the other electrode and is connected to the *negative* pole in d.c. circuits so that there is a tendency for metal melted from the rod electrode to be carried into the weld by the current. This process and its modifications are used very extensively at present. The *Kjell-*

berg system uses a metal electrode sheathed with a composition which reduces oxidation; this electrode is connected to the positive, and the work is connected to the negative terminal. In the *Quasi-Arc* system Fig. 107 (4), a special sheathed metal electrode is laid along the joint and an arc is struck between one end of this electrode and the work (by using a carbon rod). The electrode sheathing is rendered conducting by the heat of the arc and the electrode is progressively melted into the joint, the stock metal being simultaneously heated sufficiently to secure a homogeneous weld.

A.C. versus D.C.; Metal versus Carbon Electrodes.—These alternatives have formed the subject of innumerable controversies, and it may safely be said that neither form of current and neither type of electrode is invariably the best. The a.c. arc is more difficult to maintain than the d.c. arc, but it yields thoroughly satisfactory results in the hands of an experienced welder. Voltage reduction of a.c. may be by static transformer, no motor-generator being required. It is claimed that a.c. secures deeper penetration of heat yet reduces the risk of burning the weld. Metal electrodes burn with a shorter arc than carbon electrodes, and hence require more skilled manipulation; the cross section of the metal electrode and arc is less than that of the carbon arc, so that good local penetration of heat is secured, and there is reduced risk of fused metal flowing onto unfused metal, which would cause poor adhesion. The fact that a metal electrode can be used without a filler-strip is often a great advantage, particularly when welding vertical or overhead joints. The material used for metal electrodes ranges from soft iron to special manganese and other alloys. Nothing can yet be said definitely concerning the influence of the composition of metal electrodes on the quality of the weld. The Welding Committee of the U.S.A. Emergency Fleet Corporation recommend that the following percentages be not exceeded:—C, 0·18; Mn, 0·55; P, 0·05; S, 0·05; Si, 0·08. It is claimed for coated metal electrodes that the sheathing (usually of lime, borax, or other flux) reduces oxidation of metal in the arc and on the work. Coating with ordinary whitewash improves the steadiness of burning of non-uniform electrodes. Flux deposited on the weld from sheathed electrodes should be removed before adding another layer of metal.

Applications of Arc Welding.—Carbon arc welding is used for filling blow-holes in castings, building up lugs and gear teeth, etc., and for welding sheet metal, though, in the latter field, the metal electrode process is frequently employed. The carbon arc is very useful for cutting purposes and for heavy welding repairs such as the trimming and jointing of broken axles, loco-



CARBON ELECTRODE
MAGNET
CARBON ELECTRODE
FILLER STRIP
METAL BLOCK
METAL ELECTRODE
METAL BLOCK
SPECIAL SHEATHING ON METAL ELECTRODE.
METAL BLOCK
COMPLETED WELD
A
B
C
D
E
F
G
H
J
K
L
M
N
125 v. D.C.
REACTANCE
A
G
M
S
P
A
B
D
C
D
D1
A
B
3RD. 2ND. 1ST
1ST.
e d c b a
3RD
4TH
2ND
1ST
d c b a
3RD
4TH
2ND

Fig. 107.

motive frames, tramway rails and so on. Metal arc welding is often claimed to give a better class of weld, but there is little to choose between carbon and metal arc welding if they be practised by qualified men. Among the many applications in which metal arc welding is employed, mention may be made of: Building thin sheet boxes and tanks; welding flanges to pipes; replacing riveting in ship construction, etc.; building up worn wheel flanges, tyres, axles, couplings, etc. A patch located by dowel pins and then welded in position is often a useful means of repairing broken castings. Arc welding may be used quite satisfactorily for iron and steel plates exceeding $\frac{1}{8}$ in. thickness, and even for thinner plates; but much reliance must not be placed on the mechanical strength of welds in cast iron.

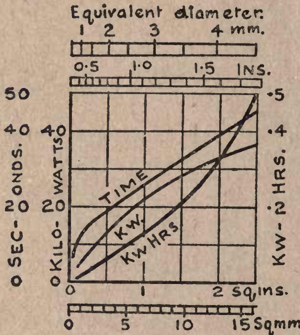


FIG. 107 (8).

Typical Joints for Arc Welds.—The joints shown in Fig. 107(5) require little explanation. Except in the case of very thin sheet, the edges of the joints are bevelled so as to ensure good penetration of the arc and a sound weld throughout. Generally, the weld should be built up to a greater thickness than the stock, and the weld should lap over the edge of the bevel. The angle of a single bevel may be 30° or 45° according to the thickness of the metal and the accessibility of the joint; when both parts are bevelled the total angle enclosed is usually about 60° and sometimes 90°. Thin plates may be butt-welded without chamfering the edges or the latter may be turned up and welded as at M, this arrangement reducing the risk of burning through thin sheet. Fig. 107 (5), N shows a similar method for welding the ends in steel barrels; *a* represents the end plate; *b* the body of the barrel and *c*, *d*, are internal and external hoops clamped in

place whilst all four pieces are welded together as shown. The longitudinal weld in the body is a plain butt joint.

Arc Welding Data.—For carbon-arc welding a carbon 1 in. diam. is commonly employed; the current consumption is then 200 amp. or more at 85–100 v.; filler-strip is used as required. Using the Quasi-Arc system about 9 in. per min. can be welded during the actual welding period, the size of electrode and the current being chosen to suit the thickness of the plate. The following data are applicable to welding with ordinary metal electrodes, using from 20 to 25 v. at the arc, compared with 40 or 50 v. for carbon arcs.

Thickness of Plate In.	Electrode Diam. In.	Current Amps.
Up to $\frac{1}{8}$	$\frac{1}{16}$–$\frac{3}{32}$	50-85
$\frac{1}{8}$ to $\frac{5}{8}$	$\frac{1}{8}$	125–150
	$\frac{5}{32}$	150–200
Over $\frac{5}{8}$	$\frac{3}{16}$	200–250
	$\frac{1}{4}$	300–400

The speed of welding varies with the dimensions and difficulty of the work and, using metal electrodes, varies from about 2 ft. per hr. for first class work of average difficulty up to 7 ft. per hr. under exceptionally favourable conditions. Owing to the influence of the width and depth of the weld, it is better to specify the weight of metal deposited per hr. This ranges from $1\frac{1}{2}$ or 2 lb. per hr. in high class plate welding up to 4 lb. per hr. in welding tram track, etc. The energy consumption is from $2\frac{1}{2}$ to 4 kw. hr. (average $3\frac{1}{2}$ kw. hr.) per lb. of deposit. Strengths up to 60,000 lb. per sq. in. have been obtained in welds in mild steel and the joint can always be built up to greater strength than the stock.

Inspecting Arc Welds.—Visual inspection of the weld, for surface finish, length and uniformity of deposits, gives a good general guide to the quality of the workmanship. Judicious chipping at the edges of deposits discloses imperfect adhesion. Testing with paraffin discloses even the finest fissures extending right through the weld. X-ray tests are useful in special cases, but the detection of hidden defects is very difficult, and at present it is necessary to depend primarily on the skill and care of the operator.

Current Supply for Arc Welding.—There are many special welding sets now on the market most of which have advantages of their own in point of efficiency, suitability for scattered or centralized load as the case may be, or in making it difficult for

the operator to weld incorrectly. The voltage available *at the arc* should not be higher than 40 or 50 v. with carbon and 20 or 25 v. with metal electrodes, otherwise a long arc may be maintained, and this results in oxidation and porosity. Merely to connect the arc in series with ballast resistance across d.c. supply is wasteful, and the more so the higher the supply voltage. On the other hand, this arrangement is simple and reliable, and a motor generator supplying 60 to 75 v. on open circuit is a very satisfactory means of supplying a number of welders located close together. The welding circuits are connected in parallel to the generator. A special *constant current* d.c. generator or a.c. transformer facilitates maintenance of the arc and permits a short arc to be used without excessive current flow and too rapid deposition of metal; on the other hand, it also facilitates maintenance of a long arc, which gives poor results. A number of arcs may be operated in series if reasonably close together. When using a.c., the secondary of a constant current transformer may serve the primaries of individual welding transformers connected in series; there is no direct electrical connection between the welding circuit and the series circuit. The *constant energy* d.c. system yields maximum efficiency, but the equipment is relatively complicated. Each welder is served by a motor-generator or balancer set, and the system is, therefore, well suited to the supply of welders scattered over a wide area. Fig. 107 (6) illustrates a special constant energy equipment which serves a welding circuit connected between the positive main and the common terminal of a motor-generator set (through the variable, differential series field of the generator). The armature currents of both machines feed the arc, and the difference between line and generator voltage is absorbed by the motor, so that about 56 % of the energy consumption may be utilized in the arc, compared with, say, 22 % when using simple series resistance control. An approximation to constant energy is obtained in a.c. welding by using a transformer with high magnetic leakage, so that the voltage decreases automatically as the current increases. No ballast resistance is required, hence the efficiency is high, but the high leakage results in low power factor (often under 50 %); low power factor means idle copper losses, but affects only the generator circuit if a motor-generator be used.

Protecting the Eyes and Flesh.—Painful burns and permanent serious damage to eyesight are caused by neglecting to use properly tinted goggles and suitable masks, etc. Complete protection is obtained by using asbestos gloves, breast shield and apron, and suitable goggles (preferably incorporated in a helmet which screens the face and neck). A hand screen with tinted window may be used instead of a helmet if one hand can be spared to hold it. Two red glasses, one green glass and a clear

cover glass to protect the others, form a safe combination. When possible, the welder should work within an enclosure which protects other workmen from the arc.

Percussive Welding—This is a special system of arc welding applicable to wires up to $\frac{1}{10}$ in. diam. The wires to be welded are held by two clamps connected respectively to the terminals of a large electrolytic condenser charged by d.c. The lower clamp is stationary and the other is loaded by weights and runs freely between vertical guides. The wires being in place and the condenser charged, the upper clamp is released. At the moment the wires come into contact there is an explosive discharge, the heat of which melts the surface layers of the metal. At the same time, the force of impact drives scale, etc., out of the joint and secures thorough cohesion between the parts. Owing to the practically instantaneous completion of the weld and the extremely local nature of the fusion, it is possible to weld practically any two metals by this process, even such dissimilar metals as tin and platinum. A slight burr is raised at the weld, but the nature of the metal on either side of the latter is unchanged.

Resistance Welding.—This system of welding depends upon heat developed by the passage of a heavy current through the area of contact between the pieces to be joined. According to the type of joint and electrodes employed, one speaks of butt-welding or spot-, point-, line- or seam-welding. The requisite local heating effect is due to the relatively high contact resistance between the parts to be welded. The very high current density needed is best secured by using a.c. supply and a step-down transformer, which is situated as close as possible to the work in order to reduce the length of low tension conductor.

Butt Welding.—The massive single-turn secondary S of a step-down transformer PS Fig. 107 (7) terminates in two clamps AB, which are arranged (1) To grip quickly the pieces to be welded; (2) to bring the abutting surfaces into contact; (3) to "upset" and complete the joint when welding heat is attained. The current is switched on when the pieces come in contact and switched off automatically as the joint is upset. The jaws, the electrical and mechanical adjustments, and the timing of the machine must be set to suit each job, as also must the distance from the joint at which the pieces are gripped, the clamp being nearer the joint on the smaller piece (when welding unequal parts) so that cooling by conduction may be equal in the two pieces. Butt welding is essentially a process suitable for repetition work, and semi-automatic and automatic machines have been developed which make possible enormous production. The process may be applied to welding any size from, say, 24 S.W.G.

up to 4 in. steel bar, heavy steel tyres and so on. Chain welding is performed by automatic machines with excellent results. Different metals may be welded together, allowance being made for differences in thermal conductivity and melting point by adjusting the distance from the joint to the clamps. Particularly useful applications are in joining band saws and in securing high-speed tool steel to carbon steel shanks. A.C. supply at 50 cycles and from 100 to 400 v. is generally employed, the secondary current (at 1 to 4 volts) being regulated by variable primary tappings or resistance. The approximate energy consumption and time to make butt welds on iron and steel are shown in Fig. 107 (8).

Spot and Seam Welding—Fig. 107 (9) illustrates spot welding; the single-turn secondary of a step-down transformer delivers low voltage current of heavy amperage to the cylindrical electrodes AB. As good contact as possible is obtained at CC, so that heat development is concentrated at D between the plates. When welding heat is attained, mechanical pressure is applied to the electrodes and a circular weld is produced which is generally so strong that the adjoining metal will tear away before the weld fails. In order to prevent the plate being left with a depression in the surface above the weld, a filling-disc may be placed under the electrode as at D, Fig. 107 (10), or it may be placed between the plates as at D^1. The latter arrangement is also useful in concentrating the heat when welding thick plates together, or sheet metal onto a solid block. Spot welding is a very satisfactory and economical substitute for riveting in many applications ranging from thinnest sheet metal goods (domestic utensils, etc.) up to $\frac{3}{4}$ in. ship plates and the like. According to circumstances, the demand of a spot welder may be anything from 5 to 75 kw. and from 30 to 1000 welds may be made per hour, each weld occupying from $\frac{1}{2}$ sec. to 3 secs. (Incidentally, the very short duration of each current flow makes the load a difficult one to meter accurately.) Light applications of spot welding are to fixing handles on utensils; fixing nails to metal plates for holding lagging in place; and building sheet metal goods of all kinds. About 1000 spot welds in $\frac{1}{64}$ in. sheet may be made with an energy consumption of 1 kw. hr. At the other extreme, spot welds between $\frac{1}{2}$ in. or $\frac{3}{4}$ in. steel plates require a current of 30,000 to 50,000 amp. for 15 sec. or more, and the application of mechanical pressure up to 25,000 or 30,000 lb. The transformer primary may be of copper tubing through which cooling-water is circulated; and the secondary of heavy copper bars with mica and asbestos insulation. The electrodes are water cooled and renewable copper tips are used for heavy service. Other applications of spot welding are to fixing bonds and fish-plates to rails, fixing rungs to metal ladders, and plugging mis-

placed holes. A spot welder with carbon electrodes has been used to braze together coil ends in large armatures. *Seam welding* is identical with spot welding except that roller electrodes are used Fig. 107 (11) so as to produce a continuous joint. A water-tight joint in thin utensils, paint cans, etc., can be made at the rate of 2 to 4 ft. per min. Thin sheets or components may be provided with indentations or grooves which are then placed together as in Fig. 107 (12) and welded. This *point-* or *line-welding* system is useful in building double walls for ovens and for securing stiffness with light construction. The electrodes are of relatively large section, so that welding is effected at a number of points or lines at once.

A spot welder fitted with cupped electrodes may be used to *heat and close rivets* Fig. 107 (13). The process is rapid and noiseless, and the rivet is most heated where it has to be upset, hence a very close joint is secured. The process may be used to rivet sheets together or to secure bonds to rails. From 100 to 200 $\frac{3}{8}$ in. rivets may be closed per hour by a 10 kva. welder; and rivets up to $1\frac{1}{4}$ in. $\times$ 6 in. may be closed by a 30 kva. welder.

Fig. 107 (14) illustrates *arc-spot welding.* One plate only is drilled as at A, and the holes are filled by a metal-electrode arc, the deposited plug also welding the plates together as at B. This process is claimed to be cheaper than spot welding, and is certainly more convenient in the case of wide plates for which a spot welder of sufficient jaw depth is very heavy.

Welding Hints—The personal element is of enormous importance, especially in arc welding. Metal-arc welding should generally be performed with a short arc and with a semi-circular movement of the electrode to work slag, etc., out of the deposit. The layer onto which metal is deposited should itself be molten. When building up flanges, apply semi-tangential, *not* radial layers of metal. Never weld over bolt-heads, but it is permissible to weld over a rivet head. If a long seam is to be welded, the plates should be clamped, otherwise there will be warping, due to contraction stresses, as indicated in Fig. 107 (15). A usual allowance for contraction is $1\frac{1}{2}$ % of the length of the weld; clamps are released as the weld approaches them; if the joint closes too quickly, the rate of welding should be accelerated if possible. It is recommended that a long joint be arc welded in 6 in. sections by the *back-welding* method illustrated in Fig. 107 (16). Rectangular and round patches should be welded as indicated by the numbered arrows in Fig. 107 (17), each joint being made by the back-welding method. Clean surfaces are essential in fusion welding, and though a certain amount of scale *between* plates facilitates local heating for spot welding it involves the risk of weak strata in the weld. Sound weld-metal to the full depth or over the full area of the weld is the end to be attained.

ELECTRIC HEATING AND COOKING.

THE passage of electric current through any conductor develops an amount of heat which varies with the square of the current and the resistance of the conductor. By using different conductor materials, different cross sections and different lengths, any desired quantity of heat may be developed, and practically any temperature may be produced between that of the atmosphere and that of the electric arc. Theoretically 1 kw.-hr. of electrical energy corresponds to 3440 B.Th.U. and, according to circumstances, from 70% to 95% or more of this thermal equivalent can be realised in electric heating applications. On the other hand, about 2 lbs. coal are burnt in the average modern central station per kw.-hr. of electrical energy produced. In other words, about 26,000 B.Th.U. are expended, in a coal-fired station, to produce a quantity of electrical energy which will yield only 3440 B.Th.U. Nevertheless, there is a sound economic case for electric heating and cooking, based on the following advantages :—Absence of dirt and fumes; convenience and accuracy of control; instant service secured by closing a switch; automatic (thermostatic) control if desired; safety and reliability. Each of these main headings covers advantages in many respects and directions. Even more noticeably in industrial than in domestic service, electric heating renders service which could be secured by no other means. Also, *in almost every application,* electric heating equipment has a far higher thermal efficiency than the corresponding coal- or gas-heated equipment, so that what the latter gains in respect of cheap heat it loses, to a great extent, by wasteful application. Owing to this factor, there is little to choose between the direct ("fuel") costs of electric and gas cooking, and where electric cooking is more expensive, the difference is compensated by its advantages in other respects. When heat is not required to warm the room as well, there is no doubt that coal ranges are more costly than electric ovens; 3 or 4 tons burned in the former being replaced by current generated from 1 ton of coal. Saving of coal by this means, and the entire saving of coal where hydro-electric energy can be employed, are now of vital importance in every country.

Room Heaters.—The two principal types of electric heaters for warming rooms are radiators and convectors. The heating element of the *convector* is operated at a comparatively low temperature and its action consists in warming air in contact with it. The warmed air rises, cooler air takes its place, and thus a circulation is set up which results in the whole of the air in

the room being warmed gradually. The heating element of the *radiator*, on the other hand, is operated at red heat. There is still some warming effect by convection but a large proportion of the total heat is radiant, *i. e.* it proceeds in straight lines in all directions and *does not heat the air appreciably.** On the other hand, any solid object in the path of the radiated heat is warmed immediately and it is quite easy to scorch an article placed in front of a radiator; this could never be done in the case of a convector. Obviously a radiator is particularly useful when one wishes to experience an immediate sense of warmth; seated before a radiator one may feel quite comfortable though the temperature of the air in the room is about freezing. Convectors, on the other hand, or radiators with a large proportion of convected heat, are used to warm the whole room so that one may be comfortable even though not in the direct rays from the heater. Heating by convection is not suitable for rooms which are occupied for short periods and on short notice. The higher the room, the longer it is before air at working level is brought to a stated temperature by convected heat, and it is very desirable that convectors be of ample heating capacity, so that a room may be warmed quickly, the power expenditure being then reduced to normal. For all practical purposes, the heat produced per kw.-hr. expended is the same for radiators as for convectors (the energy equivalent of the luminous radiation from a radiator being very small) but the distinction between the "mechanism" of the two methods of heating is very important.

Radiators.—Lamp-type radiators consist of carbon filament lamps, the filament being operated at bright red heat (corresponding to 8 or 10 watts per c.p.). The bulbs are frosted to reduce glare and to increase the apparent heat-giving area. Each lamp consumes 250 watts, and usually 3 or 4 lamps are mounted in front of a polished reflector. Hot-bar radiators employ coils of nichrome wire or strip, this material being an alloy of nickel and chromium which has the valuable property of withstanding oxidation even when operated at bright red heat in air. A mere film of oxide forms on the surface of the wire and this is sufficient to insulate adjacent turns of the coil. A spiral of suitable size and length of wire is wound on or in a quartz tube; *or* the spiral is supported by grooves or by ridges and lugs formed in a fireclay base. An important feature is the provision of substantial terminal clips. A hot-bar radiator consuming about 500 watts is useful for small rooms, cabins, etc. A powerful local effect may be obtained if the heater be at the focus of a suitable reflector,

* Such heating of the air as does occur where a radiator is used is due to convection from the heater and to secondary heating effected by warmed furniture, etc.

indeed a heater of this type mounted in a suitable stand may be used also to heat a kettle or other utensil. Larger radiators are made, up to 3 kw. or over, and most of them are easily portable; the addition of a hob on which to stand a kettle is usually a convenience.

Convectors.—Nichrome resistance coils may again be used, but they are operated only at black heat, a small glow lamp behind a ruby window being generally added to improve the appearance. About $1\frac{1}{2}$ kw. is the smallest rating desirable, and if more than 3 or 4 kw. is required, it is better to use two or more convectors at different parts of the room, rather than one very large apparatus. Hot-bar radiators may be arranged to produce much convective effect, but they are then apt to "burn" the air, so that it is usual to obtain as much radiant effect as possible, by the use of polished reflector-screens. The ordinary type of hot-water radiator may be about half-filled with water and fitted near the bottom with an "immersion heater," *i. e.* a resistance element suitably insulated for complete immersion in water. The complete heater then acts principally by convection.

Thermal Storage.—The principle of thermal storage is employed (*a*) To meet a fluctuating demand for, say, hot water by the steady consumption of a relatively small current; (*b*) To store heat during periods of light load on the power-station, for use during the remainder of the 24 hours. In either case, a resistance element is embedded in a heat-storage medium which may be a massive block of iron or stone, or a quantity of sand. In connection with hot-water supply, an iron block may be heated continuously by a small-power resistance element and, when the demand for hot water exceeds the heating capacity of the element, heat is withdrawn from the iron. The load factor of such a heater is 100%, hence a specially low supply tariff can generally be obtained. The consumption may be anything from 50 to 1000 watts, the corresponding yield of hot water being from 5 to 140 gall. per 24 hrs. at 110° F. The second type of thermal storage is used in Switzerland for heating rooms. Electrical energy is used during the night hours, and possibly during the midday hour, to heat a block of stone or a mass of sand, the outer surface of which gives off heat continuously. The expenditure of 3 kw. for 8 hours in heating the storage medium produces approximately the same result in heating the room as the continuous expenditure of 1 kw. High thermal conductivity in the storage medium and good external lagging are necessary in the case of a water heater, but low thermal conductivity, low surface temperature and liberal mass of material are essential in a storage which is to heat a room as uniformly as possible throughout the day. From 3 to 5 kw. is generally consumed

during the "charging" period, and the best apparatus is considered to be an element of nichrome or silundum embedded in sand.

Power Expenditure in Room Heating.—The power to be expended in warming a room depends upon the severity of the climate and upon the window area, wall thickness, and number and aspect of exterior walls. Suitable distribution of heaters in large rooms does much for uniform and efficient heating. In general, heaters should be placed near air inlets and never beneath air outlets (*e. g.* a fireplace with open chimney). For medium-sized rooms in ordinary English homes, an allowance of $1\frac{1}{2}$ to 2 watts per cu. ft. of room space is sufficient for rapid warming from cold; subsequently, from 1 to $1\frac{1}{2}$ watts per cu. ft. should maintain a comfortable temperature.

Electrically Heated Clothing.—Two types of heaters are used to warm clothing for airmen and motorists. One method is to sew into the garments a crinkled nichrome wire covered with asbestos, electrical connections being completed by plugs and sockets. The other method is to use heating units consisting of flat nichrome strips wound on and between mica plates and provided with snap-connections. These heating elements are placed in pockets in the garments. Dowsing elements supplied for this service are operated at 12 volts and require current as follows : Waistcoat $2\frac{1}{2}$ amps. (30 watts); gloves $1\frac{1}{2}$ amp. (18 watts per pair; socks 1 amp. (12 watts). Electrically heated quilts for hospital use, comprise a network of flexible, insulated resistance wires placed between an inner fabric which conducts heat readily and an outer fabric which reduces loss of heat to a minimum.

Electric Cooking.—Electric cooking equipment includes self-contained utensils with integral heating units; hot plates; ovens, hot cupboards and composite cooking ranges. In each case the advantages secured are cleanliness, safety; flexibility and convenience of location and operation; freedom from fumes; less wastage and improved flavour of food; low working cost; easy, accurate control and certain repetition of results. Whereas the thermal efficiency of the domestic coal range is about 3%, and that of the gas rings 20 or 25%, self-contained electric utensils have 95% or higher thermal efficiency, whilst hot plates should yield from 50 to 70% efficiency. The pleasant conditions associated with electric cooking are particularly important.

A simple method of determining the overall efficiency of a kettle or saucepan, etc., is to measure the temperature rise $t°$ F. produced in p pints of water by the expenditure of w watts in the heater for m minutes. Then the thermal efficiency is pt 2190 (wm)%.

Heat Control.—The constancy of voltage in modern supply networks results in the same heating being always derived from a particular resistance element or combination of elements. By various combinations of elements in series and parallel, heat control may be provided over a wide range in a number of definite steps. Since the heat developed varies with C^2 R, halving the current reduces the heat to one-quarter and so on. Fig. 108 (1) illustrates heat control by varying the number of heating elements in circuit; this control is applicable to any number of elements, each of which has its own make and break switch. Fig. 108 (2) illustrates substantially the same arrangement except that each switch controls several heating elements in parallel, which may

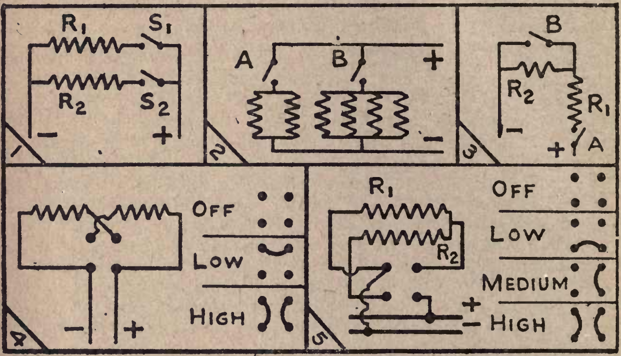


FIG. 108.

be distributed, for example, on the sides of an oven. In the particular case illustrated by Fig. 108 (2), closing switch A yields $\frac{1}{3}$ full heat; closing B yields $\frac{2}{3}$ full heat; and closing both switches yields full heat. In Fig. 108 (3), closing switch A places two heaters in series across the supply; subsequently closing switch B short-circuits the heater R_2. If $R_1 = R_2$, the heat developed in the two cases is as $\frac{1}{2}$: 1. In Fig. 108 (4), a rotary 4-terminal switch, yielding connections as shown inset, places the heating elements in series for low heat and in parallel for high heat, thus providing a heat range of $\frac{1}{4}$: 1. Fig. 108 (5) provides an intermediate "heat" by connecting: (*a*) Two elements in series ($\frac{1}{4}$ heat); (*b*) Element R_1 alone ($\frac{1}{2}$ heat); (*c*) Both elements in parallel (full heat). Series-parallel control of four elements will provide :—Low heat by four elements in series; medium heat by two elements in

series; full heat by two elements in parallel. Uniform distribution of heat and uniform deterioration of heaters is favoured by passing equal current (reduced when necessary) through all the heating elements rather than reduce the heating by cutting one or more elements out of circuit.

During the warming-up period, the power absorbed by the heating circuit is considerably higher than the steady value. The standard convention is that the "loading" is the power taken by the apparatus when the marked pressure has been applied for 5-min. The B.E.S.A. specification states that if the total loading of an oven or cooking table exceeds 2½ kw., the heating elements are to be divided into two approximately equal circuits, each terminating in a pair of terminals and arranged so that they can be separately fused, controlled and connected.

Self-contained Utensils.—These are compact, convenient and efficient though naturally more costly in the first place than the corresponding utensils for external heating. Usually, a nichrome resistance is insulated electrically by a mica support and wrappings and is placed in good thermal contact with the block of metal forming the bottom of the saucepan or kettle, or the sole of the iron, etc.

Hot Plates.—There are two distinct types of hot plates, *viz.* the *enclosed* and the *open* or *radiant* types. In the enclosed type, the heating element is placed below and in good thermal contact with a metal block, on which is placed the utensil to be heated. The surface of the hot plate *and* the bottom surface of the utensil should be quite flat and clean because the slightest air film between these surfaces represents great thermal resistance. According to circumstances, the hot plate is designed for a max. temperature of from 200° F. (for keeping food warm) up to 600°–700° F. (for cooking). The mica insulation used in enclosed hot plates cannot withstand higher temperature than 700° F. but there is no such limit in open hot plates, which employ bare nichrome wire, carried by a refractory insulating base, protected against mechanical damage, and operated at bright red heat (*see* Table I). The open hot plate has higher thermal efficiency than the enclosed type where the heating of small quantities of liquid is concerned.

Grills are practically inverted hot plates of the open type and, as such, need no special mention. They may be used for toasting, or a light framework may be used, fitted for table use.

Ovens.—Nichrome heating elements are generally employed. There is considerable variation in the mechanical details by which suitable distribution and control of heating, are secured, together with sufficient protection yet easy accessibility of

elements. In one type of oven, the casing is nickel plated, brightly polished to reduce radiation but unlagged except for an air jacket between the double walls. The other construction resembles that of gas ovens, a casing of sheet steel or cast iron being enamelled internally and lagged externally. Such an oven will retain cooking heat for an hour or more, current being switched off after full heat is attained; it is, in fact, a "hot box" cooker which is electrically heated in the first place. Flexible heat distribution is secured by placing elements at the top, bottom and sides of the oven and by grouping these in suitable control circuits. With "full heat" (say 1 kw. per cu. ft., *see* Table I.), cooking temperature should be reached in 15 or 20 mins. Subsequently, the power consumption may be reduced to ½ or ¼ the maximum. An important factor in convenient and economical operation is the provision of a switchboard (usually on the wall above the cooker) containing control switches, indicating "pilot" lamps and enclosed fuses. An oven with a grill and several

TABLE I.—TYPICAL CONSUMPTIONS OF HEATING AND COOKING APPARATUS.

Apparatus.	Watts per sq. in.; cu. in.; or lb., etc.	Usual consumption Watts.
Radiator, cabin size	1 to 1½ watts/cu. ft., warmed	500–750
,, villa size	1½ to 2 w./cu. ft., warmed	1000–2000
,, for large rooms	1½ to 2 w./cu. ft., warmed	3000–4000
Hot plate, enclosed (boiling), 6 to 9 in. diameter	25 to 15 w./sq. in.	500–1000
Hot plate, enclosed (canteen or factory), 100 to 650 sq. in.	15 to 5 w./sq. in.	1000–3000
Hot plate, open type, 6 to 9 in. diam.	50 to 30 w./sq. in.	1000–2000
Porringer, milk warmer, etc., 2 to 4 pints	225 to 175 w./pint	500–750
Kettle, 2 to 4 pints	375 to 225 w./pint	750–900
Urn or boiling pans—		
1 to 2 gall.	1000 w./gall.	1000–2000
4 ,, 6 ,,	750 to 600 w./gall.	3000–3500
10 ,, 20 ,,	500 w./gall.	5000–10,000
Thermal storage bulk-water heater, 20 gall.	15 to 20 w./gall.	350
Grill, 75 to 200 sq. in.	20 to 12 w./sq. in.	800–2500
Hot cupboard, 16 cu. ft.	220 w./cu. ft.	3500
Oven, 2½ to 6½ cu. ft.	1200 to 800 w./cu. ft.	1500–6000
Iron, 4 to 6 lb.	75 w./lb.	300–450
Glue pot, 2 to 8 pints	400 to 250 w./pint	800–2000
Melting pot (solder, wax, etc.), 140 to 220 cu. in.	6½ to 7 w./cu. in.	900–1500

hot plates provides all the facilities of a gas stove. An energy consumption of 1½ to 2 units per person per day is a liberal allowance for electric cooking in small families. The average decreases to ½ unit per head in schools and institutions, etc. American experience indicates an average consumption of 125 units per range per month (based on 25,000 ránges); other investigations indicate a consumption of 80 to 90 units per month for a family of two, and 100 units for a family of four.

The British Standard Cooking Range (B.E.S.A. Specification 106/1920) comprises (1) An *oven* with shelf racks, shelves, heating elements and control equipment. (2) A *cooking table* with hot plates or heaters for boiling, simmering and grilling, and a warming cupboard, the whole complete with heating elements and control equipment. Two sizes of oven and two sizes of cooking table are specified. The leading particulars of both are as follows :—

	Size A. Suitable for 5 persons	Size B. Suitable for 10 persons
OVEN :—		
Clear inside dimensions, Height × depth × width, ins.	18 × 13 × 14	21 × 15 × 16
Max. overall dimensions, ins.	27 × 23 × 30	27 × 25 × 32
Max. loading, watts	2000	3000
Max. time to reach 350° F. above room tempr.,[1] mins.	35	35
Max. energy for ditto., kw.-hr.	1	1¼
Max. power to maintain 250° F, above room tempr., watts	550	750
COOKING TABLE :—		
Max. overall dimensions, Height × depth × width, ins.	12 × 23 × 30	12 × 25 × 32
Hot plates,[2] number 8 in. diam.	1	2
Hot plates, number 7 in. diam.	1	1
Outside dimensions of rectangular grill, ins.	13 × 9	13 × 9
Min. grilling space, ins.	9 × 8	9 × 8
Max. loading of grill, watts	800–1200	800–1200

[1] The oven temperature being measured at centre of horizontal plane (A) 4 in. or (B) 5 in. below oven top.

[2] Full loading of hot plates : 8 in. 1000 to 1500 watts; 7 in. 800 to 1250 watts. At max. load (1500 and 1250 watts respectively) the temperature of a standard testing disc (made and used as described in the specification) shall reach 350° F. above room temperature in 20 min. The time taken shall be inversely proportional to the loading, but shall not exceed 30 min. The energy required to establish this temperature rise shall not exceed 0·5 kw.-hr. for an 8 in., and 0·45 kw.-hr. for a 7 in. plate. The power required to maintain this temperature shall not exceed 550 watts.

The **principal constructional features** are as follows; reference should be made to the report for details: Electrical connections and elements to be insulated with mica, porcelain, silica or other tough and incombustible material capable of withstanding 1200° F. continuously. Beads of solid, insulating, incombustible material are to be used as dielectric for conductors other than heating elements. The dielectric between all live parts and frame must withstand 1000 v., a.c. for 1 min., after "full heat" has been applied for 5 min. Metal parts not designed to carry current must be bonded and connected to a socket for a 0·007 sq. in. earthing cable. It must be impossible to touch any bare conductor accidentally without first removing a guard. If the switches (or cut-outs) are on a separate panel their connecting leads must be within a metallic tube fixed firmly to the panel and to the cooker. A cut-out must be fixed on each pole of each separately controlled circuit, unless one pole is earthed, in which case only the other pole may be fused. The reliability test specified is 3 hours continuously at marked pressure and maximum rating with the oven empty and door closed, and both with and without utensils on the hot plates. The total height to top of cooking table in a combined oven and cooking table is not to exceed 39 in.

The oven heating elements are to be at or near the top of the oven and at or near the bottom of the sides. Heating elements are to be self-contained, easily fixed and removed, and connected to terminals by iron, nickel or other approved conductors of not less than four times the current carrying capacity of the heating element. If the terminal block for the elements is inside the oven, another terminal block is required outside for the main cables. Vertically hinged oven doors must be capable of being hung from either side. Provision for ventilation and for a thermometer is required near the top of the door. Four recesses on the oven top register with projections on the base of the cooking table. The arrangement is to be such as to provide a convenient warming chamber between the oven and the top of the cooking table.

Water Heater.—Electric heating is quick, convenient and also very economical for heating small quantities of water, owing to the high thermal efficiency of self-contained utensils, immersion heaters or hot plates, compared with gas rings or coal fires. Where, however, large quantities of water have to be heated, electric heating is generally out of the question owing to the much lower cost per 1000 B.Th.U. of heat derived from slow combustion coke fires. A detailed investigation of the problem is to be found in *Electrical Engineering Practice* (by J. W. Meares). Where the quantity of hot water required would not justify the use of a coke-boiler, where electricity is cheap, and where the

cleanliness and convenience of electric heating are specially valuable, a thermal-storage system may be used. A variable quantity of water at max. temperature (rather than a tankful of warm water at variable temperature) is obtainable by winding a heating element round the bottom of a circulating tube outside the tank Fig. 108 (6) or by using an immersion heater at the bottom of a circulating tube within the tank Fig. 108 (7). Good lagging is most important and the hot water outlet pipe should first go *downwards* so as to eliminate heat loss by convection therein; downward conduction of heat in a water column occurs very slowly. Thermostatic control is economical. Provision should be made so that sludge and scale do not settle on the heating element. *Electric geysers* are very convenient but rather costly to operate. Since a quantity of water has to be heated rapidly, the power consumption is heavy and of poor load factor, unless

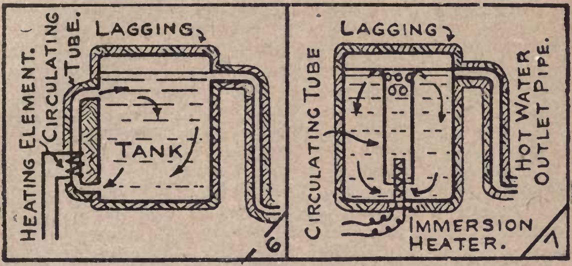


FIG. 108 (6, 7).

use be made of thermal storage in an iron block. A tap attachment in which water flows over a hot resistance element as it emerges is quite suitable for heating rapidly small quantities of water. In countries where coal is abnormally scarce and costly and where hydro-electric energy is cheap and abundant, the latter has been used to raise steam for power purposes; generally, however, it is much better to use electric motors and eliminate steam plant under such circumstances.

Miscellaneous Applications and Apparatus.—The *electric iron* is probably used more commonly than any other electrically heated device. An element of nichrome wire or strips is wound on a mica former or in grooves in a refractory support and it is arranged that as much as possible of the heat shall go into the sole of the iron and as little as possible into the top and handle. *Soldering irons* are built on the same principle as immersion heaters; and *glue pots* are merely saucepans with self-contained heating elements.

Very economical heating of passenger cars and garages is made possible by utilising the heat developed in motor control resistance in the first case and in battery charging resistances in the second case. Electrically heated industrial ovens and furnaces range from low-temperature bread-baking and enamelling ovens to arc furnaces capable of melting the most refractory materials. Amongst other industrial applications of electric heating may be mentioned the heating of paper rollers, hat shapers, glove stretchers, drying and seasoning rooms, vacuum ovens, etc. High temperature furnaces, including iron and steel furnaces, form a class of their own.

Selection and Operation of Equipment.—The principal points to be looked for when selecting heating or cooking apparatus may be enumerated approximately in the following order of importance :—Suitable heat distribution, capacity and control; operating efficiency; electrical insulation; earthing of frame and of the covering of metal-sheathed conductors; substantial, electrically insulated and mechanically protected connecting-wire or cable; substantial terminals (flat or strip contacts are generally preferable to the pin type), well protected against mechanical damage and accidental contact; conveniently placed switchboard with substantial switches and, where required, fuses and pilot lamps; heating elements protected against shock, short circuit, and the spilling of liquids; standardised heating elements, mounted with due allowance for expansion and easily replaced; easy cleaning of all parts; construction as light and compact as compatible with mechanical strength; low first cost.

For earthing purposes, stranded wire armouring may be employed or a cable with a special earthing core may be used. It is very desirable that the frame of all heating and cooking apparatus be earthed if the circuit voltage exceeds 110 volts; for pressures exceeding 200 volts and for power exceeding 1 kw., earthing should be regarded as essential. An electric iron should never be left unattended with the switch closed. A pilot lamp in each branch circuit of heating and cooking apparatus helps to avoid waste of current and premature burning-out of elements. Separate circuits should have independent branch fuses and the size of supply conductors should be that dictated by the I.E.E. Wiring Rules or that required to limit the maximum pressure drop to 2 volts, whichever is larger.

Current economy in the use of hot plates and ovens may be effected by switching off shortly before completion of the cooking operation, in order to utilise heat stored in the apparatus. Such is the accuracy with which electric cooking performances can be repeated, that it is worth while to note the best possible performance and then conduct operations on a time basis.

NOTES ON ELECTRIC LIFTS.

Driving.—The most economical and efficient method of driving an electric lift is to have the motor directly coupled to the winding machine, and operated by a reversing controller, so the current is only consumed when lift is actually working.

Controlling.—For a lift in ordinary use when an attendant is in charge, the simplest and best method is to control the lift by means of a switch in the car. In the case of lifts exceeding a speed of 200 ft. per minute, the control should be fitted with a slowing down arrangement, to secure gradual and smooth stopping. For lifts in private houses, automatic push-button control is generally provided, with suitable provisions so that the lift can be operated by any person wishing to use it either from the landing or from inside the car.

Motor.—The motor should be arranged to start under heavy loads, and to run at a constant speed, with a large overload factor. The field-magnets are generally compound wound, the series turns assisting the shunt winding and giving a high initial torque with a small expenditure of energy. The series turns are generally short-circuited as soon as the required speed has been attained. The winding gear should be noiseless and efficient, and should be constructed with steel worm, and worm wheel with cast-iron centre and phosphor bronze rim. This should be enclosed in a cast-iron case, with the worm preferably arranged underneath the wheel, and the thrust of the worm shaft should be taken by ball thrust bearings.

Speeds, etc.—Passenger lifts for public buildings are usually run at from about 150 ft. to 350 ft. per minute. Lifts in private houses with automatic operation, are usually run at 120 ft. to 150 ft. per minute. The latest practice is to fit the driving machines with large sheaves, turned to suit four steel-wire lifting ropes. Where the machine is fitted overhead, the sheaves should be of sufficient diameter to span from the centre of the car to the centre of the counter-balance weight. The balance weight should be equal to the weight of the car, and half the live load.

$1\frac{3}{4}$ in. circumference steel ropes are generally used for suspending lifts, these being used four together. The safe working load on each is taken at 15 cwts. The safe working load on steel ropes including weight of rope $= \frac{1}{10}$ breaking weight for high speed lifts, and $\frac{1}{8}$ breaking weight for ordinary lifts.

It is advisable that motor gearing should not have a higher mechanical efficiency than 50 per cent., otherwise there is a danger of the load taking charge and driving backwards.

THERMOMETER SCALES.

F.	C.	F.	C.	F.	C.	F.	C.	F.	C.
0	−17·78	50	10·00	100	37·78	150	65·56	200	93·34
1	−17·23	51	10·56	101	38·34	151	66·11	201	93·90
2	−16·67	52	11·11	102	38·90	152	66·67	202	94·45
3	−16·11	53	11·67	103	39·45	153	67·23	203	95·00
4	−15·56	54	12·23	104	40·00	154	67·78	204	95·56
5	−15·00	55	12·78	105	40·56	155	68·34	205	96·11
6	−14·45	56	13·34	106	41·11	156	68·90	206	96·27
7	−13·90	57	13·90	107	41·57	157	69·45	207	97·23
8	−13·34	58	14·45	108	42·23	158	70·00	208	97·78
9	−12·78	59	15·00	109	42·78	159	70·56	209	98·34
10	−12·23	60	15·56	110	43·34	160	71·11	210	98·90
11	−11·67	61	16·11	111	43·90	161	71·67	211	99·45
12	−11·11	62	16·67	112	44·45	162	72·23	212	100·00
13	−10·56	63	17·23	113	45·00	163	72·78	213	100·56
14	−10·00	64	17·78	114	45·56	164	73·34	214	101·11
15	−9·45	65	18·34	115	46·11	165	73·90	215	101·67
16	−8·89	66	18·89	116	46·67	166	74·45	216	102·23
17	−8·34	67	19·45	117	47·23	167	75·00	217	102·78
18	−7·78	68	20·00	118	47·78	168	75·66	218	103·34
19	−7·23	69	20·56	119	48·34	169	76·11	219	103·90
20	−6·67	70	21·11	120	48·90	170	76·67	220	104·45
21	−6·11	71	21·67	121	49·45	171	77·23	225	107·23
22	−5·56	72	22·23	122	50·00	172	77·78	230	110·00
23	−5·00	73	22·78	123	50·56	173	78·34	235	112·78
24	−4·45	74	23·34	124	51·11	174	78·90	240	115·56
25	−3·90	75	23·90	125	51·67	175	79·45	245	118·34
26	−3·34	76	24·45	126	52·23	176	80·00	250	121·11
27	−2·78	77	25·00	127	52·78	177	80·56	255	123·90
28	−2·23	78	25·56	128	53·34	178	81·11	260	126·67
29	−1·67	79	26·12	129	53·90	179	81·67	265	129·45
30	−1·11	80	26·67	130	54·45	180	82·23	270	132·23
31	−0·56	81	27·23	131	55·00	181	82·78	275	135·00
32	0·00	82	27·78	132	55·56	182	83·34	280	137·78
33	0·56	83	28·34	133	55·11	183	83·90	285	140·56
34	1·11	84	28·89	134	56·67	184	84·45	290	143·34
35	1·67	85	29·45	135	57·23	185	85·00	295	146·11
36	2·23	86	30·00	136	57·78	186	85·56	300	148·90
37	2·78	87	30·55	137	58·34	187	86·11	310	154·45
38	3·34	88	31·11	138	58·90	188	86·67	320	160·00
39	3·90	89	31·67	139	59·45	189	87·23	330	165·56
40	4·45	90	32·22	140	60·00	190	87·78	340	171·11
41	5·00	91	32·78	141	60·56	191	88·34	350	176·67
42	5·56	92	33·33	142	61·11	192	88·90	360	182·23
43	6·11	93	33·89	143	61·67	193	89·45	370	187·78
44	6·67	94	34·45	144	62·23	194	90·00	380	193·34
45	7·23	95	35·00	145	62·78	195	90·56	390	198·90
46	7·78	96	35·56	146	63·34	196	91·11	400	204·45
47	8·34	97	36·11	147	63·90	197	91·67	450	232·23
48	8·89	98	36·67	148	64·45	198	92·23	500	260·00
49	9·45	99	37·23	149	65·00	199	92·78	550	287·75

PULLEY SPEED CALCULATIONS.

As the circumference of a pulley is directly proportional to its diameter, the latter can be used in all questions of speeds of pulleys and gear wheels. In belt pulley calculations the thickness of the belt should be added to the pulley diameter if close results are required. In the case of rope pulleys, the diameter should be measured to the centre of the rope, and in spur gear the *pitch* diameter, and not the outside diameter, must be taken.

The rules relating to the diameters and speeds of pulleys are given conveniently in the following statement, in which R.P.M. indicates revolutions per minute.

Given.	Required.	Rule.
Diameter of driving pulley, Diameter of driven pulley, R.P.M. of driving pulley.	R.P.M. of driven pulley.	Multiply diameter of driving pulley by its R.P.M., and divide by diameter of driven pulley.
Diameter of driving pulley, R.P.M. of driving pulley, R.P.M. of driven pulley.	Diameter of driven pulley.	Multiply diameter of driving pulley by its R.P.M., and divide by R.P.M. of driven pulley.
Diameter of driving pulley, Diameter of driven pulley, R.P.M. of driven pulley.	R.P.M. of driving pulley.	Multiply diameter of driven pulley by its R.P.M., and divide by diameter of driving pulley.
Diameter of driven pulley, R.P.M. of driven pulley, R.P.M. of driving pulley.	Diameter of driving pulley.	Multiply diameter of driven pulley by its R.P.M., and divide by R.P.M. of driving pulley.

As a check on such calculations, it should be noted that any pulley diameter when multiplied by its revolutions per minute is equal to any other pulley diameter when multiplied by *its* revolutions per minute.

For a compound drive such as a train of gears or a compound belt drive multiply the diameters of all the driving wheels together, and the diameters of the driven wheels together. Dividing the first product by the second, and multiplying by the revolutions per minute of the first driving pulley, will give the revolutions per minute of the last driven pulley.

HORSE-POWER OF LEATHER BELTS
PER INCH OF WIDTH.

Velocity of Belt in Feet per Minute.	Best Oak-tanned Belts.			Best Link or Chain Belts.					
	Single Belts.	Light Double Belts.	Heavy Double Belts.	in. $\frac{3}{8}$	in. $\frac{1}{2}$	in. $\frac{5}{8}$	in. $\frac{3}{4}$	in. $\frac{7}{8}$	in. 1
100	0·15	0·21	0·27	0·13	0·15	0·17	0·20	0·24	0·27
200	0·30	0·42	0·55	0·25	0·29	0·35	0·40	0·47	0·55
300	0·45	0·64	0·82	0·38	0·44	0·52	0·60	0·71	0·82
400	0·61	0·85	1·09	0·51	0·58	0·69	0·80	0·95	1·09
500	0·76	1·06	1·36	0·64	0·73	0·86	1·00	1·18	1·36
600	0·91	1·27	1·64	0·76	0·87	1·04	1·20	1·42	1·64
700	1·06	1·49	1·91	0·89	1·02	1·21	1·40	1·65	1·91
800	1·21	1·70	2·18	0·92	1·16	1·38	1·60	1·89	2·18
900	1·36	1·91	2·45	1·05	1·31	1·55	1·80	2·13	2·45
1000	1·51	2·12	2·73	1·27	1·45	1·73	2·00	2·36	2·73
1100	1·67	2·33	3·00	1·40	1·60	1·90	2·20	2·60	3·00
1200	1·82	2·55	3·27	1·53	1·75	2·07	2·40	2·84	3·27
1300	1·97	2·76	3·55	1·65	1·89	2·25	2·60	3·07	3·55
1400	2·12	2·97	3·82	1·78	2·04	2·42	2·80	3·31	3·82
1500	2·27	3·18	4·09	1·91	2·18	2·59	3·00	3·55	4·09
1600	2·42	3·39	4·36	2·04	2·33	2·76	3·20	3·78	4·36
1700	2·58	3·61	4·64	2·16	2·47	2·94	3·40	4·02	4·64
1800	2·73	3·82	4·91	2·29	2·62	3·11	3·60	4·25	4·91
1900	2·88	4·03	5·18	2·42	2·76	3·28	3·80	4·49	5·18
2000	3·03	4·24	5·45	2·55	2·91	3·45	4·00	4·73	5·45
2100	3·18	4·45	5·73	2·67	3·05	3·63	4·20	4·96	5·73
2200	3·33	4·67	6·00	2·80	3·20	3·80	4·40	5·20	6·00
2300	3·49	4·88	6·27	2·93	3·35	3·97	4·60	5·44	6·27
2400	3·64	5·09	6·55	3·05	3·49	4·15	4·80	5·67	6·55
2500	3·79	5·30	6·82	3·18	3·64	4·32	5·00	5·91	5·82
2600	3·94	5·52	7·09	3·24	3·78	4·49	5·20	6·15	7·09
2700	4·09	5·73	7·36	3·28	3·85	4·66	5·40	6·38	7·36
2800	4·24	5·94	7·64	3·31	3·86	4·73	5·60	6·62	7·64
2900	4·39	6·15	7·91	3·32	3·87	4·78	5·80	6·85	7·91
3000	4·50	6·36	8·18	3·31	3·86	4·75	5·97	7·09	8·18
3100	4·60	6·58	8·45	3·30	3·85	4·73	5·96	7·33	8·45
3200	4·69	6·79	8·70	3·28	3·82	4·71	5·94	7·37	8·73
3300	4·77	7·00	8·86	3·24	3·77	4·70	5·92	7·35	8·88
3400	4·84	7·21	8·96	3·19	3·71	4·64	5·87	7·32	8·86
3500	4·90	7·31	9·06	3·13	3·61	4·50	5·78	7·26	8·80
3600	4·95	7·40	9·16	3·05	3·50	4·37	5·67	7·16	8·73
3700	4·99	7·48	9·24	2·96	3·39	4·26	5·55	7·01	8·58
3800	5·03	7·54	9·29	2·84	3·28	4·15	5·41	6·87	8·41
3900	5·06	7·60	9·34	2·72	3·13	4·02	5·20	6·70	8·27
4000	5·08	7·64	9·37	2·58	2·95	3·84	5·01	6·48	8·04
4200	5·10	7·70	9·38	2·27	2·55	3·37	4·52	5·98	7·51
4500	5·07	7·69	9·27	1·64	1·77	2·45	3·68	5·05	6·55
5000	4·82	7·42	8·75	0·42	0·55	0·61	1·55	2·78	4·32

HORSE-POWER OF COTTON DRIVING ROPES.

(C. N. PICKWORTH).

Velocity in feet per minute.	Diameter of Ropes in Inches.									
	$\frac{3}{4}$	$\frac{7}{8}$	1	$1\frac{1}{8}$	$1\frac{1}{4}$	$1\frac{3}{8}$	$1\frac{1}{2}$	$1\frac{5}{8}$	$1\frac{3}{4}$	2
2000	5·1	7·0	9·1	11·	14·2	17·3	20·5	24·1	28·0	36·5
2100	5·3	7·3	9·5	12·1	14·9	18·0	21·4	25·1	29·2	38·1
2200	5·6	7·6	9·9	12·6	15·5	18·8	22·3	26·2	30·4	39·7
2300	5·8	7·9	10·2	13·0	16·1	19·4	23·1	27·1	31·5	41·1
2400	6·0	8·1	10·6	13·4	16·6	20·1	23·9	28·1	32·6	42·5
2500	6·2	8·4	11·0	13·9	17·2	20·8	24·7	29·0	33·7	44·0
2600	6·4	8·7	11·3	14·4	17·8	21·5	25·5	30·0	34·8	45·4
2700	6·6	8·9	11·7	14·8	18·3	22·1	26 3	30·9	35 9	46·8
2800	6·8	9·2	12·0	15·2	18·8	22·8	27·1	31·8	36·8	48·1
2900	6·9	9·4	12·3	15·6	19·3	23·3	27·8	32·5	37·8	49·3
3000	7·1	9·6	12·6	16·0	19·8	23·9	28·4	33·3	38·7	50·4
3100	7·3	9·9	12·9	16·3	20·2	24·4	29·0	34·1	39·6	51·6
3200	7·4	10·1	13·1	16·6	20·6	24·9	29·6	34·8	40·4	52·7
3300	7·6	10·3	13·4	17·0	21·0	25·4	30·2	35·4	41·2	53·8
3400	7·7	10·6	13·7	17·3	21·5	26·0	30·8	36·2	42·0	54·6
3500	7·8	10·7	13·9	17·6	21·8	26·4	31·4	36·8	42·8	55·8
3600	8·0	10·8	14·1	17·9	22·1	26·8	31·8	37·4	43·3	56·5
3700	8·1	11·0	14·3	18·2	22·4	27·1	32·3	37·9	44·0	57·3
3800	8·2	11·1	14·5	18·4	22·7	27·5	32·7	38·4	44·5	58·2
3900	8·3	11·3	14·7	18·5	23·0	27·8	33·1	38·8	45·0	58·8
4000	8·4	11·4	14·8	18·7	23·2	28·1	33·4	39·2	45·5	59·4
4100	8·4	11·5	15·0	19·0	23·5	28·4	33·7	39·6	46·0	60·0
4200	8·5	11·5	15·1	19·1	23·7	28·6	34·0	39·9	46·3	60·4
4300	8·6	11·6	15·2	19·2	23·8	28·8	34·2	40·2	46·6	60·8
4400	8·6	11·7	15·3	19·3	23·9	28·9	34·4	40·4	46·8	61·2
4500	8·7	11·7	15·3	19·4	24·0	29·0	34·5	40·5	47·0	61·4
4600	8·7	11·8	15·4	19·4	24·1	29·1	34·6	40·6	47·1	61·5
4700	8·7	11·8	15·4	19·5	24·1	29·2	34·7	40·7	47·2	61·6
4800	**8·7**	**11·8**	**15·4**	**19·5**	**24·2**	**29·2**	**34·7**	**40·8**	**47·3**	**61·7**
4900	8·7	11·8	15·4	19·5	24·1	29·2	34·7	40·7	47·2	61·6
5000	8·7	11·8	15·4	19·4	24·1	29·1	34·6	40·6	41·1	61·5
5100	8·7	11·7	15·3	19·4	24·0	28·9	34·5	40·5	47·0	61·2
5200	8·6	11·7	15·2	19·3	23·9	28·8	34·3	40·2	46·7	61·0
5300	8·5	11·6	15·1	19·2	23·7	28·7	34·1	40·0	46·4	60·6
5400	8·5	11·5	15·0	19·0	23·5	28·4	33·8	39·6	46·0	60·0
5500	8·4	11·4	14·8	18·8	23·2	28·1	33·4	39·2	45·5	59·4
5600	8·3	11·2	14·7	18·6	23·1	27·8	33·1	38·8	45·2	58·8
5700	8 2	11·1	14·4	18·3	22·6	27·3	32·5	38·1	44·3	57·8
5800	8·1	10·9	14·2	18·0	22·3	27·0	32·1	37·6	43·7	57·1
5900	7·9	10·7	14·0	17·8	22·0	26·6	31·6	37·0	43·0	56·2
6000	7·7	10·6	13·9	17·6	21·7	26·3	31·2	36·7	42·5	55 5
6500	6·8	9·2	12·0	15·2	18·8	22·8	27·1	31·8	36·9	48·1
7000	5·4	7·4	9·6	12·2	15·0	18·2	21·4	25·4	29·5	38·4

HORSE-POWER OF SPUR WHEELS.

(PER REVOLUTION PER MINUTE AND PER INCH OF BREADTH.)

Pitch in Inches.	Diameter of Wheel.																				
	ft in 0 6	ft in 0 9	ft in 1 0	ft in 1 3	ft in 1 6	ft in 1 9	ft in 2 0	ft in 2 3	ft in 2 6	ft in 2 9	ft in 3 0	ft in 3 6	ft in 4 0	ft in 4 6	ft in 5 0	ft in 5 6	ft in 6 0	ft in 7 0	ft in 8 0	ft in 9 0	ft in 10 0
1	·006	·009	·012	·015	·018	·021	·024	·027	·030	·033	·036	·042	·048	·054	·060	·066	·072	·084	·096	·108	·120
1¼	·007	·011	·015	·019	·022	·026	·030	·034	·037	·041	·045	·052	·060	·067	·075	·082	·030	·105	·120	·135	·150
1½	·009	·013	·018	·023	·027	·031	·036	·040	·045	·050	·054	·063	·072	·081	·090	·099	·108	·126	·144	·162	·180
1¾	·010	·015	·021	·026	·032	·036	·042	·047	·052	·058	·053	·073	·084	·094	·105	·115	·126	·147	·168	·189	·210
2	·012	·018	·024	·030	·036	·042	·048	·054	·060	·066	·072	·084	·096	·108	·120	·132	·144	·168	·192	·216	·240
2¼	..	..	·027	·034	·040	·047	·054	·061	·067	·073	·081	·094	·108	·121	·135	·148	·162	·189	·216	·243	·270
2½	..	..	·030	·038	·044	·052	·052	·068	·074	·082	·090	·104	·120	·134	·150	·164	·180	·210	·240	·270	·300
2¾	..	..	..	·041	·049	·053	·066	·074	·032	·091	·099	·115	·132	·148	·165	·181	·198	·231	·264	·297	·330
3	..	..	..	·045	·054	·063	·072	·081	·090	·099	·108	·126	·144	·162	·180	·198	·216	·252	·288	·324	·360
3¼	..	..	..	·049	·058	·068	·078	·038	·097	·107	·117	·136	·156	·175	·195	·214	·234	·273	·312	·350	·390
3½	..	..	..	..	·054	·072	·084	·094	·104	·116	·126	·146	·168	·188	·210	·230	·252	·294	·336	·378	·420
3¾	..	..	..	..	·067	·078	·090	·101	·112	·124	·135	·157	·180	·202	·225	·247	·270	·315	·360	·405	·450
4	..	..	..	..	..	·084	·096	·108	·120	·132	·144	·168	·192	·216	·240	·264	·288	·336	·384	·432	·480
4¼	..	..	..	..	..	·089	·102	·115	·127	·140	·153	·178	·204	·230	·255	·280	·306	·357	·408	·460	·510
4½	..	..	..	..	..	·094	·108	·122	·134	·148	·162	·188	·216	·242	·270	·295	·324	·378	·432	·486	·540
4¾	..	..	..	..	..	..	·114	·128	·142	·157	·171	·199	·228	·256	·285	·313	·342	·399	·455	·512	·570
5	..	..	..	..	..	..	·120	·135	·150	·165	·180	·210	·240	·270	·300	·330	·360	·420	·480	·540	·600
5½	..	..	..	..	..	..	..	·148	·164	·182	·198	·230	·264	·296	·330	·362	·396	·462	·528	·594	·660
6	..	..	..	..	..	..	..	·162	·180	·198	·216	·252	·288	·324	·360	·396	·432	·504	·576	·648	·720

TABLE OF GAUGES.

Gauge Number.	English Imperial Legal Standard.	Birmingham or Stubbs, or "English Standard."	B'ham, for Sheets not Iron or Steel.	Birmingham, for Iron Sheets.	Lancashire, one of Holtzapffels.	Warrington, or Rylands.	Old English, for Brass, etc.	Whitworth's English Standard.	Brown & Sharpe American St'd'rd.
7/0	·500	..	..	..	..	·500	..	..	..
6/0	·464	..	..	..	..	·468+	..	..	..
5/0	·432	..	..	..	..	·437+	..	..	..
4/0	·400	·454	..	..	..	·406+	..	..	·460
3/0	·372	·425	..	..	..	·375	..	..	·409+
2/0	·348	·380	..	..	..	·343+	..	..	·364+
0	·324	·340	..	..	..	·326	..	..	·324+
1	·300	·300	·004	·312+	·227	·300	..	·001	·289+
2	·276	·284	·005	·281+	·219	·274	..	·002	·257+
3	·252	·259	·008	·250	·209	·250	..	·003	·229+
4	·232	·238	·010	·234+	·20[illegible]	·229	..	·004	·204+
5	·212	·220	·012	·218+	·201	·209	..	·005	·181+
6	·192	·203	·013	·203+	·198	·191	..	·006	·162+
7	·176	·180	·015	·187+	·195	·174	..	·007	·144+
8	·160	·165	·016	·171+	·192	·159	..	·008	·128+
9	·144	·148	·019	·156+	·191	·146	..	·009	·114+
10	·128	·134	·024	·140+	·190	·133	..	·010	·101+
11	·116	·120	·029	·125	·189	·117	..	·011	·090+
12	·104	·109	·034	·112+	·185	·100	..	·012	·080+
13	·092	·095	·036	·100	·180	·090	..	·013	·071+
14	·080	·083	·041	·087+	·177	·079	·083	·014	·064+
15	·072	·072	·047	·075	·175	·069	·072	·015	·057+
16	·064	·065	·051	·062+	·174	·062+	·065	·016	·050+
17	·056	·058	·057	·056+	·169	·053	·058	·017	·045+
18	·048	·049	·061	·050	·167	·047	·049	·018	·040+
19	·040	·042	·064	·043+	·164	·041	·040	·019	·035+
20	·036	·035	·067	·037+	·160	·036	·035	·020	·031+
21	·032	·032	·072	·034+	·157	·031+	·031+	..	·028+
22	·028	·028	·074	·031+	·152	·028	·029+	·022	·025+
23	·024	·025	·077	·028+	·150	..	·027	..	·022+
24	·022	·022	·082	·025	·148	..	·025	·024	·020+
25	·020	·020	·095	·023+	·146	..	·023	..	·017+
26	·018	·018	·103	·021+	·143	..	·020+	·026	·015+
27	·016+	·016	·113	·020+	·141	..	·018+	..	·014+
28	·014+	·014	·120	·018+	·138	..	·016+	·028	·012+
29	·013+	·013	·114	·017+	·134	..	·015+	..	·011+
30	·012+	·012	·126	·015+	·125	..	·013+	·030	·010+
31	·011+	·010	·133	·014+	·118	..	·012+	..	·008+
32	·010+	·009	·143	·012+	·115	..	·011+	·032	·007+
33	·010	·008	·145	..	·111	..	·010+	..	·007+
34	·009+	·007	·148	..	·109	..	·009+	·034	·006+
35	·008+	·005	·158	..	·107	..	·009	..	·005+
36	·007+	·004	·169	..	·105	..	·007+	·036	·005
37	·006+	..	..	..	·102	..	·006+	..	·004+
38	·006	..	..	..	·100	..	·005+	·038	·003+
39	·005+	..	..	..	·098	..	·005	..	·003+
40	·004+	..	..	..	·096	..	·004+	·040	·003+
41	·004+	..	..	..	·095	..	..	..	..
42	·004	..	..	..	·091	..	..	..	..

COMPOUND CONVERSION FACTORS.

ENGLISH TO METRICAL.

Pounds per lineal foot . .	×	1·488	= kilos. per lineal metre.
Pounds per lineal yard . .	×	0·496	= kilos. per lineal metre.
Tons per lineal foot . . .	×	3333·33	= kilos. per lineal metre.
Tons per lineal yard . . .	×	1111·11	= kilos. per lineal metre.
Pounds per mile . . .	×	0·2818	= kilos. per kilometre.
Pounds per square inch . .	×	0·0703	= kilos. per square centimetre.
Tons per square inch . .	×	1·575	= kilos. per square millimetre.
Pounds per square foot . .	×	4·883	= kilos. per square metre.
Tons per square foot . .	×	10·936	= tonnes per square metre.
Tons per square yard . .	×	1·215	= tonnes per square metre.
Pounds per cubic yard . .	×	0·5933	= kilos. per cubic metre.
Pounds per cubic foot . .	×	16·020	= kilos. per cubic metre.
Tons per cubic yard . . .	×	1·329	= tonnes per cubic metre.
Grains per gallon . . .	×	0·01426	= grammes per litre.
Pounds per gallon . . .	×	0·09983	= kilos. per litre.
Gallons per square foot . .	×	48·905	= litres per square metre.
Inch-tons	×	25·8	= kilogrammetres.
Foot-pounds	×	0·1382	= kilogrammetres.
Foot-tons	×	0·309	= tonne-metres.
Horse-power	×	1·0139	= force de cheval.
Pounds per H.P. . . .	×	0·477	= kilos. per cheval.
Square feet per H.P. . .	×	0·0916	= square metre per cheval.
Cubic feet per H.P. . .	×	0·0279	= cubic metre per cheval.
Heat units	×	0·252	= calories.
Heat units per square foot .	×	2·713	= calories per square metre.

METRICAL TO ENGLISH.

Kilos. per lineal metre . . .	×	0·672	= pounds per lineal foot.
Kilos. per lineal metre . . .	×	2·016	= pounds per lineal yard.
Kilos. per lineal metre . . .	×	0·0003	= tons per lineal foot.
Kilos. per lineal metre . . .	×	0·0009	= tons per lineal yard.
Kilos. per kilometer	×	3·548	= pounds per mile.
Kilos. per square centimetre . .	×	14·223	= pounds per square inch.
Kilos. per square millimetre . .	×	0·635	= tons per square inch.
Kilos. per square metre . . .	×	0·2048	= pounds per square foot.
Tonnes per square metre . . .	×	0·0914	= tons per square foot.
Tonnes per square metre . . .	×	0·823	= tons per square yard.
Kilos. per cubic metre . . .	×	1·686	= pounds per cubic yard.
Kilos. per cubic metre . . .	×	0·0624	= pounds per cubic foot.
Tonnes per cubic metre . . .	×	0·752	= tons per cubic yard.
Grammes per litre	×	70·12	= grains per gallon.
Kilos. per litre	×	10·438	= pounds per gallon.
Litres per square metre . . .	×	0·0204	= gallons per square foot.
Kilogrammetres	×	7·233	= foot-pounds.
Kilogrammetres	×	0·0387	= inch-tons.
Tonne-metres	×	3·23	= foot-tons.
Force de cheval	×	0·9863	= horse-power.
Kilos. per cheval	×	2·235	= pounds per H.P.
Square metre per cheval . . .	×	10·913	= square foot per H.P.
Cubic metre per cheval . . .	×	35·806	= cubic feet per H.P.
Calories	×	3·968	= heat units.
Calories per square metre . . .	×	0·369	= heat units per square foot.

METRICAL EQUIVALENTS OF BRITISH IMPERIAL WEIGHTS AND MEASURES.

MEASURES OF LENGTH.

English.			French.		
Inch .	=	2·539954 centimetres.	Millimetre	=	0·03937in.
Foot .	=	3·047950 decimetres.	Centimetre	=	0·393708in.
Yard .	=	0·91438325 metre.	Decimetre	=	3·937079in.
Fathom .	=	1·82876696 metre.	Metre . .	=	39·37079in. 3·2808992ft. 1·093633yd.
Pole .	=	5·02911 metres.	Kilometre .	=	1093·633yds.
Furlong	=	201·16437 metres.	Myriametre	=	6·2138 miles.
Mile .	=	1609·3146 metres.	Nœud .	=	Eng. nautical mile.
Nautical Mile	=	1855·020 metres.			

SUPERFICIAL MEASURES.

Sq. in.	=	0·000645125 sq. metre.	Acre .	=	0·404671 hectare.
Sq. ft.	=	0·0928980 sq. metre.	Sq. metre .	=	1·193623 sq. yd.
Sq. yd.	=	0·836082 sq. metre.	Are . .	=	0·098845 rood.
Rod .	=	25·291430 sq. metre.	Hectare .	=	2·471143 acres.
Rood .	=	10·116750 ares.			

WEIGHTS.

(Troy) Grain	=	0·065 gramme.	Gramme .	=	15·433 troy grains. 0·643dwt.
Pennyweight	=	1·555 gramme.	Kilogrm. .	=	15,433·0 troy grains. 2·679 troy lb. 2·205 avoir. lb.
Ounce . .	=	31·103 grammes.	Myriagramme or 10kilos.	=	22·0462125lb.
Pound (5760grs.)	=	373·220 grammes. 0·373220 kilogr'me.	Quintal or 100kilos. .	=	220·462125lb.
(Avoirdps.) Dram.	=	1·77 gramme.	Tonneau or Millier . 1000kilos.	=	0·9842059 of a ton.
Ounce . .	=	28·35 grammes.			
Pound (7000grs.)	=	453·57 grammes. 0·45357 kilogr'me.			
Cwt. . .	=	50·8 kilogrammes.			
Ton . .	=	1016·0 kilogrammes.			

DECIMAL EQUIVALENTS OF FRACTIONAL PARTS OF AN INCH.

Fractions.	Decimals.	Fractions.	Decimals.	Fractions.	Decimals.	Fractions.	Decimals.
1-64	·015625	17-64	·265625	33-64	·515625	49-64	·765625
1-32	·03125	9-32	·28125	17-32	·53125	25-32	·78125
3-64	·046875	19-64	·296875	35-64	·546875	51-64	·796875
1-16	**·0625**	**5-16**	**·3125**	**9-16**	**·5625**	**13-16**	**·8125**
5-64	·078125	21-64	·328125	37-64	·578125	53-64	·828125
3-32	·09375	11-32	·34375	19-32	·59375	27-32	·84375
7-64	·109375	23-64	·359375	39-64	·609375	55-64	·859375
1-8	**·125**	**3-8**	**·375**	**5-8**	**·625**	**7-8**	**·875**
9-64	·140625	25-64	·390625	41-64	·640625	57-64	·890625
5-32	·15625	13-32	·40625	21-32	·65625	29-32	·90625
11-64	·171875	27-64	·421875	43-64	·671875	59-64	·921875
3-16	**·1875**	**7-16**	**·4375**	**11-16**	**·6875**	**15-16**	**·9375**
13-64	·203125	29-64	·453125	45-64	·703125	61-64	·953125
7-32	·21875	15-32	·46875	23-32	·71875	31-32	·96875
15-64	·234375	31-64	·484375	47-64	·734375	63-64	·984375
1-4	**·25**	**1-2**	**·5**	**3-4**	**·75**	**1**	**1·0**

AREAS AND CIRCUMFERENCES OF CIRCLES.

Dia. In.	Circumf. In.	Area. Sq. In.	Dia. In.	Circumf. In.	Area. Sq. In.	Dia. In.	Circumf. In.	Area. Sq. In.
$\frac{1}{32}$	0·098175	0·00077	2	6·28319	3·1416	5	15·7080	19·635
$\frac{3}{64}$	0·147262	0·00173	$\frac{1}{16}$	6·47953	3·3410	$\frac{1}{16}$	15·9043	20·129
$\frac{1}{16}$	0·196350	0·00307	$\frac{1}{8}$	6·67588	3·5466	$\frac{1}{8}$	16·1007	20·629
$\frac{3}{32}$	0·294524	0·00690	$\frac{3}{16}$	6·87223	3·7583	$\frac{3}{16}$	16·2970	21·135
$\frac{1}{8}$	0·392699	0·01227	$\frac{1}{4}$	7·06858	3·9761	$\frac{1}{4}$	16·4934	21·648
$\frac{5}{32}$	0·490874	0·01917	$\frac{5}{16}$	7·26493	4·2000	$\frac{5}{16}$	16·6897	22·166
$\frac{3}{16}$	0·589049	0·02761	$\frac{3}{8}$	7·46128	4·4301	$\frac{3}{8}$	16·8861	22·691
$\frac{7}{32}$	0·687223	0·03758	$\frac{7}{16}$	7·65763	4·6664	$\frac{7}{16}$	17·0824	23·221
$\frac{1}{4}$	0·785398	0·04909	$\frac{1}{2}$	7·85398	4·9087	$\frac{1}{2}$	17·2788	23·758
$\frac{9}{32}$	0·883573	0·06213	$\frac{9}{16}$	8·05033	5·1572	$\frac{9}{16}$	17·4751	24·301
$\frac{5}{16}$	0·981748	0·07670	$\frac{5}{8}$	8·24668	5·4119	$\frac{5}{8}$	17·6715	24·850
$\frac{11}{32}$	1·07992	0·09281	$\frac{11}{16}$	8·44303	5·6727	$\frac{11}{16}$	17·8678	25·406
$\frac{3}{8}$	1·17810	0·11045	$\frac{3}{4}$	8·63938	5·9396	$\frac{3}{4}$	18·0642	25·967
$\frac{13}{32}$	1·27627	0·12962	$\frac{13}{16}$	8·83573	6·2126	$\frac{13}{16}$	18·2605	26·535
$\frac{7}{16}$	1·37445	0·15033	$\frac{7}{8}$	9·03208	6·4918	$\frac{7}{8}$	18·4569	27·109
$\frac{15}{32}$	1·47262	0·17257	$\frac{15}{16}$	9·22843	6·7771	$\frac{15}{16}$	18·6532	27·688
$\frac{1}{2}$	1·57080	0·19635	3	9·42478	7·0686	6	18·8496	28·274
$\frac{17}{32}$	1·66897	0·22166	$\frac{1}{16}$	9·62113	7·3662	$\frac{1}{8}$	19·2423	29·465
$\frac{9}{16}$	1·76715	0·24850	$\frac{1}{8}$	9·81748	7·6699	$\frac{1}{4}$	19·6350	30·680
$\frac{19}{32}$	1·86532	0·27688	$\frac{3}{16}$	10·0138	7·9798	$\frac{3}{8}$	20·0277	31·919
$\frac{5}{8}$	1·96350	0·30680	$\frac{1}{4}$	10·2102	8·2958	$\frac{1}{2}$	20·4204	33·183
$\frac{21}{32}$	2·06167	0·33824	$\frac{5}{16}$	10·4065	8·6179	$\frac{5}{8}$	20·8131	34·472
$\frac{11}{16}$	2·15984	0·37122	$\frac{3}{8}$	10·6029	8·9462	$\frac{3}{4}$	21·2058	35·785
$\frac{23}{32}$	2·25802	0·40574	$\frac{7}{16}$	10·7992	9·2806	$\frac{7}{8}$	21·5984	37·122
$\frac{3}{4}$	2·35619	0·44179	$\frac{1}{2}$	10·9956	9·6211	7	21·9911	38·485
$\frac{25}{32}$	2·45437	0·47937	$\frac{9}{16}$	11·1919	9·9678	$\frac{1}{8}$	22·3838	39·871
$\frac{13}{16}$	2·55254	0·51849	$\frac{5}{8}$	11·3883	10·321	$\frac{1}{4}$	22·7765	41·282
$\frac{27}{32}$	2·65072	0·55914	$\frac{11}{16}$	11·5846	10·680	$\frac{3}{8}$	23·1692	42·718
$\frac{7}{8}$	2·74889	0·60132	$\frac{3}{4}$	11·7810	11·045	$\frac{1}{2}$	23·5619	44·179
$\frac{29}{32}$	2·84707	0·64504	$\frac{13}{16}$	11·9773	11·416	$\frac{5}{8}$	23·9546	45·664
$\frac{15}{16}$	2·94524	0·69029	$\frac{7}{8}$	12·1737	11·793	$\frac{3}{4}$	24·3473	47·173
$\frac{31}{32}$	3·04342	0·73708	$\frac{15}{16}$	12·3700	12·177	$\frac{7}{8}$	24·7400	48·707
1	3·14159	0·78540	4	12·5664	12·566	8	25·1327	50·265
$\frac{1}{16}$	3·33794	0·88664	$\frac{1}{16}$	12·7627	12·962	$\frac{1}{8}$	25·5254	51·849
$\frac{1}{8}$	3·53429	0·99402	$\frac{1}{8}$	12·9591	13·364	$\frac{1}{4}$	25·9181	53·456
$\frac{3}{16}$	3·73064	1·1075	$\frac{3}{16}$	13·1554	13·772	$\frac{3}{8}$	26·3108	55·088
$\frac{1}{4}$	3·92699	1·2272	$\frac{1}{4}$	13·3518	14·186	$\frac{1}{2}$	26·7035	56·745
$\frac{5}{16}$	4·12334	1·3530	$\frac{5}{16}$	13·5481	14·607	$\frac{5}{8}$	27·0962	58·426
$\frac{3}{8}$	4·31969	1·4849	$\frac{3}{8}$	13·7445	15·033	$\frac{3}{4}$	27·4889	60·132
$\frac{7}{16}$	4·51604	1·6230	$\frac{7}{16}$	13·9408	15·466	$\frac{7}{8}$	27·8816	61·862
$\frac{1}{2}$	4·71239	1·7671	$\frac{1}{2}$	14·1372	15·904	9	28·2743	63·617
$\frac{9}{16}$	4·90874	1·9175	$\frac{9}{16}$	14·3335	16·349	$\frac{1}{8}$	28·6670	65·397
$\frac{5}{8}$	5·10509	2·0739	$\frac{5}{8}$	14·5299	16·800	$\frac{1}{4}$	29·0597	67·201
$\frac{11}{16}$	5·30144	2·2365	$\frac{11}{16}$	14·7262	17·257	$\frac{3}{8}$	29·4524	69·029
$\frac{3}{4}$	5·49779	2·4053	$\frac{3}{4}$	14·9226	17·721	$\frac{1}{2}$	29·8451	70·882
$\frac{13}{16}$	5·69414	2·5802	$\frac{13}{16}$	15·1189	18·190	$\frac{5}{8}$	30·2378	72·760
$\frac{7}{8}$	5·89049	2·7612	$\frac{7}{8}$	15·3153	18·665	$\frac{3}{4}$	30·6305	74·662
$\frac{15}{16}$	6·08684	2·9483	$\frac{15}{16}$	15·5116	19·147	$\frac{7}{8}$	31·0232	76·589

AREAS AND CIRCUMFERENCES OF CIRCLES.

Dia. In.	Circumf. In.	Area. Sq. In.	Dia. In.	Circumf. In.	Area. Sq. In.	Dia. In.	Circumf. In.	Area. Sq. In.
10	31·4159	78·540	16	50·2655	201·06	22	69·1150	380·13
1/8	31·8086	80·516	1/8	50·6582	204·22	1/8	69·5077	384·46
1/4	32·2013	82·516	1/4	51·0509	207·39	1/4	69·9004	388·82
3/8	32·5940	84·541	3/8	51·4436	210·60	3/8	70·2931	393·20
1/2	32·9867	86·590	1/2	51·8363	213·82	1/2	70·6858	397·61
5/8	33·3794	88·664	5/8	52·2290	217·08	5/8	71·0785	402·04
3/4	33·7721	90·763	3/4	52·6217	220·35	3/4	71·4712	406·49
7/8	34·1648	92·886	7/8	53·0144	223·65	7/8	71·8639	410·97
11	34·5575	95·033	17	53·4071	226·98	23	72·2566	415·48
1/8	34·9502	97·205	1/8	53·7998	230·33	1/8	72·6493	420·00
1/4	35·3429	99·402	1/4	54·1925	233·71	1/4	73·0420	424·56
3/8	35·7356	101·62	3/8	54·5852	237·10	3/8	73·4347	429·13
1/2	36·1283	103·87	1/2	54·9779	240·53	1/2	73·8274	433·74
5/8	36·5210	106·14	5/8	55·3706	243·98	5/8	74·2201	438·36
3/4	36·9137	108·43	3/4	55·7633	247·45	3/4	74·6128	443·01
7/8	37·3064	110·75	7/8	56·1560	250·95	7/8	75·0055	447·69
12	37·6991	113·10	18	56·5487	254·47	24	75·3982	452·39
1/8	38·0918	115·47	1/8	56·9414	258·02	1/8	75·7909	457·11
1/4	38·4845	117·86	1/4	57·3341	261·59	1/4	76·1836	461·86
3/8	38·8772	120·23	3/8	57·7268	265·18	3/8	76·5763	466·64
1/2	39·2699	122·72	1/2	58·1195	268·80	1/2	76·9690	471·44
5/8	39·6626	125·19	5/8	58·5122	272·45	5/8	77·3617	476·26
3/4	40·0553	127·68	3/4	58·9049	276·12	3/4	77·7544	481·11
7/8	40·4480	130·19	7/8	59·2976	279·81	7/8	78·1471	485·98
13	40·8407	132·73	19	59·6903	283·53	25	78·5398	490·87
1/8	41·2334	135·30	1/8	60·0830	287·27	1/8	78·9325	495·79
1/4	41·6261	137·89	1/4	60·4757	291·04	1/4	79·3252	500·74
3/8	42·0188	140·50	3/8	60·8684	294·83	3/8	79·7179	505·71
1/2	42·4115	143·14	1/2	61·2611	298·65	1/2	80·1106	510·71
5/8	42·8042	145·80	5/8	61·6538	302·49	5/8	80·5033	515·72
3/4	43·1969	148·49	3/4	62·0465	306·35	3/4	80·8960	520·77
7/8	43·5896	151·20	7/8	62·4392	310·24	7/8	81·2887	525·84
14	43·9823	153·94	20	62·8319	314·16	26	81·6814	530·93
1/8	44·3750	156·70	1/8	63·2246	318·10	1/8	82·0741	536·05
1/4	44·7677	159·48	1/4	63·6173	322·06	1/4	82·4668	541·19
3/8	45·1604	162·30	3/8	64·0100	326·05	3/8	82·8595	546·35
1/2	45·5531	165·13	1/2	64·4026	330·06	1/2	83·2522	551·55
5/8	45·9458	167·99	5/8	64·7953	334·10	5/8	83·6449	556·76
3/4	46·3385	170·87	3/4	65·1880	338·16	3/4	84·0376	562·00
7/8	46·7312	173·78	7/8	65·5807	342·25	7/8	84·4303	567·27
15	47·1239	176·71	21	65·9734	346·36	27	84·8230	572·56
1/8	47·5166	179·67	1/8	66·3661	350·50	1/8	85·2157	577·87
1/4	47·9093	182·65	1/4	66·7588	354·66	1/4	85·6084	583·21
3/8	48·3020	185·66	3/8	67·1515	358·84	3/8	86·0011	588·57
1/2	48·6947	188·69	1/2	67·5442	363·05	1/2	86·3938	593·96
5/8	49·0874	191·75	5/8	67·9369	367·28	5/8	86·7865	599·37
3/4	49·4801	194·83	3/4	68·3296	371·54	3/4	87·1792	604·81
7/8	49·8728	197·93	7/8	68·7223	375·83	7/8	87·5719	610·27

AREAS AND CIRCUMFERENCES OF CIRCLES.

Dia. In.	Circumf. In.	Area. Sq. In.	Dia. In.	Circumf. In.	Area. Sq. In.	Dia. In.	Circumf. In.	Area. Sq. In.
28	87·9646	615·75	34	106·814	907·92	40	125·664	1256·6
1/8	88·3573	621·26	1/8	107·207	914·61	1/8	126·056	1264·5
1/4	88·7500	626·80	1/4	107·600	921·32	1/4	126·449	1272·4
3/8	89·1427	632·36	3/8	107·992	928·06	3/8	126·842	1280·3
1/2	89·5354	637·94	1/2	108·385	934·82	1/2	127·235	1288·2
5/8	89·9281	643·55	5/8	108·788	941·61	5/8	127·627	1296·2
3/4	90·3208	649·18	3/4	109·170	948·42	3/4	128·020	1304·2
7/8	90·7135	654·84	7/8	109·563	955·25	7/8	128·413	1312·2
29	91·1062	660·52	35	109·956	962·11	41	128·805	1320·3
1/8	91·4989	666·23	1/8	110·348	969·00	1/8	129·198	1328·3
1/4	91·8916	671·96	1/4	110·741	975·91	1/4	129·591	1336·4
3/8	92·2843	677·71	3/8	111·134	982·84	3/8	129·993	1344·5
1/2	92·6770	683·49	1/2	111·527	989·80	1/2	130·376	1352·7
5/8	93·0697	689·30	5/8	111·919	996·78	5/8	130·769	1360·8
3/4	93·4624	695·13	3/4	112·312	1003·8	3/4	131·161	1369·0
7/8	93·8551	700·98	7/8	112·705	1010·8	7/8	131·554	1377·2
30	94·2478	706·86	36	113·097	1017·9	42	131·947	1385·4
1/8	94·6405	712·76	1/8	113·490	1025·0	1/8	132·340	1393·7
1/4	95·0332	718·69	1/4	113·883	1032·1	1/4	132·732	1402·0
3/8	95·4259	724·64	3/8	114·275	1039·2	3/8	133·125	1410·3
1/2	95·8186	730·62	1/2	114·668	1046·3	1/2	133·518	1418·6
5/8	96·2113	736·62	5/8	115·061	1053·5	5/8	133·910	1427·0
3/4	96·6040	742·64	3/4	115·454	1060·7	3/4	134·303	1435·4
7/8	96·9967	748·69	7/8	115·846	1068·0	7/8	134·696	1443·8
31	97·3894	754·77	37	116·239	1075·2	43	135·088	1452·2
1/8	97·7821	760·87	1/8	116·632	1082·5	1/8	135·481	1460·7
1/4	98·1748	766·99	1/4	117·024	1089·8	1/4	135·874	1469·1
3/8	98·5675	773·14	3/8	117·417	1097·1	3/8	136·267	1477·6
1/2	98·9602	779·31	1/2	117·810	1104·5	1/2	136·659	1486·2
5/8	99·3529	785·51	5/8	118·202	1111·8	5/8	137·052	1494·7
3/4	99·7456	791·73	3/4	118·596	1119·2	3/4	137·445	1503·3
7/8	100·138	797·98	7/8	118·988	1126·7	7/8	137·837	1511·9
32	100·531	804·25	38	119·381	1134·1	44	138·230	1520·5
1/8	100·924	810·54	1/8	119·773	1141·6	1/8	138·623	1529·2
1/4	101·316	816·86	1/4	120·166	1149·1	1/4	139·015	1537·9
3/8	101·709	823·21	3/8	120·559	1156·6	3/8	139·408	1546·6
1/2	102·102	829·58	1/2	120·951	1164·2	1/2	139·801	1555·3
5/8	102·494	835·97	5/8	121·344	1171·7	5/8	140·194	1564·0
3/4	102·887	842·39	3/4	121·737	1179·3	3/4	140·586	1572·8
7/8	103·280	848·83	7/8	122·129	1186·9	7/8	140·979	1581·6
33	103·673	855·30	39	122·522	1194·6	45	141·372	1590·4
1/8	104·065	861·79	1/8	122·915	1202·3	1/8	141·764	1599·3
1/4	104·458	868·31	1/4	123·308	1210·0	1/4	142·157	1608·2
3/8	104·851	874·85	3/8	123·700	1217·7	3/8	142·550	1617·0
1/2	105·243	881·41	1/2	124·093	1225·4	1/2	142·942	1626·0
5/8	105·636	888·00	5/8	124·486	1233·2	5/8	143·335	1634·9
3/4	106·029	894·62	3/4	124·878	1241·0	3/4	143·728	1643·9
7/8	106·421	901·26	7/8	125·271	1248·8	7/8	144·121	1652·9

SQUARES, CUBES, AND ROOTS.

n	n^2	n^3	$\sqrt{n}$	$\sqrt[3]{n}$	n	n^2	n^3	$\sqrt{n}$	$\sqrt[3]{n}$
0	0	0	0·0000	0·0000	50	2500	125000	7·0711	3·6840
1	1	1	1·0000	1·0000	51	2601	132651	7·1414	3·7084
2	4	8	1·4142	1·2599	52	2704	140608	7·2111	3·7325
3	9	27	1·7321	1·4422	53	2809	148877	7·2801	3·7563
4	16	64	2·0000	1·5874	54	2916	157464	7·3485	3·7798
5	25	125	2·2361	1·7100	55	3025	166375	7·4162	3·8030
6	36	216	2·4495	1·8171	56	3136	175616	7·4833	3·8259
7	49	343	2·6458	1·9129	57	3249	185193	7·5498	3·8485
8	64	512	2·8284	2·0000	58	3364	195112	7·6158	3·8709
9	81	729	3·0000	2·0801	59	3481	205379	7·6811	3·8930
10	100	1000	3·1623	2·1544	60	3600	216000	7·7460	3·9149
11	121	1331	3·3166	2·2240	61	3721	226981	7·8102	3·9365
12	144	1728	3·4641	2·2894	62	3844	238328	7·8740	3·9579
13	169	2197	3·6056	2·3513	63	3969	250047	7·9373	3·9791
14	196	2744	3·7417	2·4101	64	4096	262144	8·0000	4·0000
15	225	3375	3·8730	2·4662	65	4225	274625	8·0623	4·0207
16	256	4096	4·0000	2·5198	66	4356	287496	8·1240	4·0412
17	289	4913	4·1231	2·5713	67	4489	300763	8·1854	4·0615
18	324	5832	4·2426	2·6207	68	4624	314432	8·2462	4·0817
19	361	6859	4·3589	2·6684	69	4761	328509	8·3066	4·1016
20	400	8000	4·4721	2·7144	70	4900	343000	8·3666	4·1213
21	441	9261	4·5826	2·7589	71	5041	357911	8·4261	4·1408
22	484	10648	4·6904	2·8020	72	5184	373248	8·4853	4·1602
23	529	12167	4·7958	2·8439	73	5329	389017	8·5440	4·1793
24	576	13824	4·8990	2·8845	74	5476	405224	8·6023	4·1983
25	625	15625	5·0000	2·9240	75	5625	421875	8·6603	4·2172
26	676	17576	5·0990	2·9625	76	5776	438976	8·7178	4·2358
27	729	19683	5·1962	3·0000	77	5929	456533	8·7750	4·2543
28	784	21952	5·2915	3·0366	78	6084	474852	8·8318	4·2727
29	841	24389	5·3852	3·0723	79	6241	493039	8·8882	4·2908
30	900	27000	5·4772	3·1072	80	6400	512000	8·9443	4·3089
31	961	29791	5·5678	3·1414	81	6561	531441	9·0000	4·3267
32	1024	32768	5·6569	3·1748	82	6724	551368	9·0554	4·3445
33	1089	35937	5·7446	3·2075	83	6889	571787	9·1104	4·3621
34	1156	39304	5·8310	3·2396	84	7056	592704	9·1652	4·3795
35	1225	42875	5·9161	3·2711	85	7225	614125	9·2195	4·3968
36	1296	46656	6·0000	3·3019	86	7396	636056	9·2736	4·4140
37	1369	50653	6·0828	3·3322	87	7569	658503	9·3274	4·4310
38	1444	54872	6·1644	3·3620	88	7744	681472	9·3808	4·4480
39	1521	59319	6·2450	3·3912	89	7921	704969	9·4340	4·4647
40	1600	64000	6·3246	3·4200	90	8100	729000	9·4868	4·4814
41	1681	68921	6·4031	3·4482	91	8281	753571	9·5394	4·4979
42	1764	74088	6·4807	3·4760	92	8464	778688	9·5917	4·5144
43	1849	79507	6·5574	3·5034	93	8649	804357	9·6437	4·5307
44	1936	85184	6·6332	3·5303	94	8836	830584	9·6954	4·5468
45	2025	91125	6·7082	3·5569	95	9025	857375	9·7468	4·5629
46	2116	97336	6·7823	3·5830	96	9216	884736	9·7980	4·5789
47	2209	103823	6·8557	3·6088	97	9409	912673	9·8489	4·5947
48	2304	110592	6·9282	3·6342	98	9604	941192	9·8995	4·6104
49	2401	117649	7·0000	3·6593	99	9801	770299	9·9499	4·6261

SQUARES, CUBES, AND ROOTS—(*Continued*).

n	n^2	n^3	$\sqrt{n}$	$\sqrt[3]{n}$	n	n^2	n^3	$\sqrt{n}$	$\sqrt[3]{n}$
100	10000	1000000	10·0000	4·6416	150	22500	3375000	12·2474	5·3133
101	10201	1030301	10·0499	4·6570	151	22801	3442951	12·2882	5·3251
102	10404	1061208	10·0995	4·6723	152	23104	3511808	12·3288	3·3368
103	10609	1092727	10·1489	4·6875	153	23409	3581577	12·3693	5·3485
104	10816	1124864	10·1980	4·7027	154	23716	3652264	12·4097	5·3601
105	11025	1157625	10·2470	4·7177	155	24025	3723875	12·4499	5·3717
106	11236	1191016	10·2956	4·7326	156	24336	3796416	12·4900	5·3832
107	11449	1225043	10·3441	4·7475	157	24649	3869893	12·5300	5·3947
108	11664	1259712	10·3923	4·7622	158	24964	3944312	12·5698	5·4061
109	11881	1295029	10·4403	4·7769	159	25281	4019679	12·6095	5·4175
110	12100	1331000	10·4881	4·7914	160	25600	4096000	12·6491	5·4288
111	12321	1367631	10·5357	4·8059	161	25921	4173281	12·6886	5·4401
112	12544	1404928	10·5830	4·8203	162	26244	4251528	12·7279	5·4514
113	12769	1442897	10·6301	4·8346	163	26569	4330747	12·7671	5·4626
114	12996	1481544	10·6771	4·8488	164	26896	4410944	12·8062	5·4737
115	13225	1520875	10·7238	4·8629	165	27225	4492125	12·8452	5·4848
116	13456	1560896	10·7703	4·8770	166	27556	4574296	12·8841	5·4959
117	13689	1601613	10·8167	4·8910	167	27889	4657463	12·9228	5·5069
118	13924	1643032	10·8628	4·9049	168	28224	4741632	12·9615	5·5178
119	14161	1685159	10·9807	4·9187	169	28561	4826809	13·0000	5·5288
120	14400	1728000	10·9545	4·9324	170	28900	4913000	13·0384	5·5397
121	14641	1771561	11·0000	4·9461	171	29241	5000211	13·0767	5·5505
122	14884	1815848	11·0454	4·9597	172	29584	5088448	13·1149	5·5613
123	15129	1860867	11·0905	4·9732	173	29929	5177717	13·1529	5·5721
124	15376	1906624	11·1355	4·9866	174	30276	5268024	13·1909	5·5828
125	15625	1953125	11·1803	5·0000	175	30625	5359375	13·2288	5·5934
126	15876	2000376	11·2250	5·0133	176	30976	5451776	13·2665	5·6041
127	16129	2048383	11·2694	5·0265	177	31329	5545233	13·3041	5·6147
128	16384	2097162	11·3137	5·0397	178	31684	5639752	13·3417	5·6252
129	16641	2146689	11·3578	5·0528	179	32041	5735339	13·3791	5·6357
130	16900	2197000	11·4018	5·0658	180	32400	5832000	13·4164	5·6462
131	17161	2248091	11·4455	5·0788	181	32761	5929741	13·4536	5·6567
132	17424	2299968	11·4891	5·0916	182	33124	6028568	13·4907	5·6671
133	17689	2352637	11·5326	5·1045	183	33489	6128487	13·5277	5·6774
134	17956	2406104	11·5758	5·1172	184	33856	6229504	13·5647	5·6877
135	18225	2460375	11·6190	5·1299	185	34225	6331625	13·6015	5·6980
136	18496	2515456	11·6619	5·1426	186	34596	6434856	13·6382	5·7083
137	18769	2571353	11·7047	5·1551	187	34969	6539203	13·6748	5·7185
138	19044	2628072	11·7473	5·1676	188	35344	6644672	13·7113	5·7287
139	19321	2685619	11·7898	5·1801	189	35721	6751269	13·7477	5·7388
140	19600	2744000	11·8322	5·1925	190	36100	6859000	13·7840	5·7489
141	19881	2803221	11·8743	5·2048	191	36481	6967871	13·8203	5·7590
142	20164	2863288	11·9164	5·2171	192	36864	7077888	13·8564	5·7690
143	20449	2924207	11·9583	5·2293	193	37249	7189057	13·8924	5·7790
144	20736	2985984	12·0000	5·2415	194	37636	7301384	13·9284	5·7890
145	21025	3048625	12·0416	5·2536	195	38025	7414875	13·9642	5·7989
146	21316	3112136	12·0830	5·2656	196	38416	7529536	14·0000	5·8088
147	21609	3176523	12·1244	5·2776	197	38809	7645373	14·0357	5·8186
148	21904	3241792	12·1655	5·2996	198	39204	7762392	14·0712	5·8285
149	22201	3307949	12·2066	5·3015	199	39601	7880599	14·1067	5·8383

SQUARES, CUBES, AND ROOTS—(*Continued*).

n	n^2	n^3	$\sqrt{n}$	$\sqrt[3]{n}$	n	n^2	n^3	$\sqrt{n}$	$\sqrt[3]{n}$
200	40000	8000000	14·1421	5·8480	250	62500	15625000	15·8114	6·2996
201	40401	8126001	14·1774	5·8578	251	63001	15813251	15·8430	6·3080
202	40804	8242408	14·2127	5·8675	252	63504	16003008	15·8745	6·3164
203	41209	8365427	14·2478	5·8771	253	64009	16194277	15·9060	6·3247
204	41616	8489664	14·2829	5·8868	254	64516	16387064	15·9374	6·3330
205	42025	8615125	14·3178	5·8964	255	65025	16581375	15·9687	6·3413
206	42436	8741816	14·3527	5·9059	256	65536	16777216	16·0000	6·3496
207	42849	8869743	14·3875	5·9155	257	66049	16974593	16·0312	6·3579
208	43264	8998912	14·4222	5·9250	258	66564	17173512	16·0624	6·3661
209	43671	9129329	14·4568	5·9345	259	67081	17373979	16·0935	6·3743
210	44100	9261000	14·4914	5·9439	260	67600	17576000	16·1245	6·3825
211	44521	9393931	14·5258	5·9533	261	68121	17779581	16·1555	6·3907
212	44944	9528128	14·5602	5·9627	262	68644	17984728	16·1864	6·3988
213	45369	9663597	14·5945	5·9721	263	69169	18191447	16·2173	6·4070
214	45796	9800344	14·6287	5·9814	264	69696	18399744	16·2481	6·4151
215	46225	9938375	14·6629	5·9907	265	70225	18609625	16·2788	6·4232
216	46656	10077696	14·6969	6·0000	266	70756	18821096	16·3095	6·4312
217	47089	10218313	14·7309	6·0092	267	71289	19034163	16·3401	6·4393
218	47524	10360232	14·7648	6·0185	268	71824	19248832	16·3707	6·4473
219	47961	10503459	14·7986	6·0277	269	72361	19465109	16·4012	6·4553
220	48400	10648000	14·8324	6·0368	270	72900	19683000	16·4317	6·4633
221	48841	10793861	14·8661	6·0459	271	73441	19902511	16·4621	6·4713
222	49284	10941048	14·8997	6·0550	272	73984	20123648	16·4924	6·4792
223	49729	11089567	14·9332	6·0641	273	74529	20346417	16·5227	6·4872
224	50176	11239424	14·9666	6·0732	274	75076	20570824	16·5529	6·4951
225	50625	11390625	15·0000	6·0822	275	75625	20796875	16·5831	6·5030
226	51076	11543176	15·0333	6·0912	276	76176	21024576	16·6132	6·5108
227	51529	11697083	15·0665	6·1002	277	76729	21253933	16·6433	6·5187
228	51984	11852352	15·0997	6·1091	278	77284	21484952	16·6733	6·5265
229	52441	12008989	15·1327	6·1180	279	77841	21717639	16·7033	6·5343
230	52900	12167000	15·1658	6·1269	280	78400	21952000	16·7332	6·5421
231	53361	12326391	15·1987	6·1358	281	78961	22188041	16·7631	6·5499
232	53824	12487168	15·2315	6·1446	282	79524	22425768	16·7929	6·5577
233	54289	12649337	15·2643	6·1534	283	80089	22665187	16·8226	6·5654
234	54756	12812904	15·2971	6·1622	284	80656	22906304	16·8523	6·5731
235	55225	12977875	15·3297	6·1710	285	81225	23149125	16·8819	6·5808
236	55696	13144256	15·3623	6·1797	286	81796	23393656	16·9115	6·5885
237	56169	13312053	15·3948	6·1885	287	82369	23639903	16·9411	6·5962
238	56644	13481272	15·4272	6·1972	288	82944	23887872	16·9706	6·6039
239	57121	13651919	15·4596	6·2058	289	83521	24137569	17·0000	6·6115
240	57600	13824000	15·4919	6·2145	290	84100	24389000	17·0294	6·6191
241	58081	13997521	15·5242	6·2231	291	84681	24642171	17·0587	6·6267
242	58564	14172488	15·5563	6·2317	292	85264	24897088	17·0880	6·6343
243	59049	14348907	15·5885	6·2403	293	85849	25153757	17·1172	6·6419
244	59536	14526784	15·6205	6·2488	294	86436	25413184	17·1464	6·6494
245	60025	14706125	15·6525	6·2573	295	87025	25672375	17·1756	6·6569
246	60516	14886936	15·6844	6·2658	296	87616	25934336	17·2047	6·6644
247	61009	15069223	15·7162	6·2743	297	88209	26198073	17·2337	6·6719
248	61504	15252992	15·7480	6·2828	298	88804	26463592	17·2627	6·6794
249	62001	15438249	15·7797	6·2912	299	89401	26730899	17·2916	6·6869

SQUARES, CUBES, AND ROOTS—(*Continued*).

n	n^2	n^3	$\sqrt{n}$	$\sqrt[3]{n}$	n	n^2	n^3	$\sqrt{n}$	$\sqrt[3]{n}$
300	90000	27000000	17·3205	6·6943	350	122500	42875000	18·7083	7·0473
301	90601	27270901	17·3496	6·7018	351	123201	43243551	18·7350	7·0540
302	91204	27543608	17·3781	6·7092	352	123904	43614208	18·7617	7·0607
303	91809	27818127	17·4069	6·7166	353	124609	43986977	18·7883	7·0674
304	92416	28094464	17·4356	6·7240	354	125316	44361864	18·8149	7·0740
305	93025	28372625	17·4642	6·7313	355	126025	44738875	18·8414	7·0807
306	93636	28652616	17·4929	6·7387	356	126736	45118016	18·8680	7·0873
307	94249	28934443	17·5214	6·7460	357	127449	45499293	18·8944	7·0940
308	94864	29218112	17·5499	6·7533	358	128164	45882712	18·9209	7·1006
309	95481	29503629	17·5784	6·7606	359	128881	46268279	18·9473	7·1072
310	96100	29791000	17·6068	6·7679	360	129600	46656000	18·9737	7·1138
311	96721	30080231	17·6352	6·7752	361	130321	47045881	19·0000	7·1204
312	97344	30371328	17·6635	6·7824	362	131044	47437928	19·0263	7·1269
313	97969	30664297	17·6918	6·7897	363	131769	47832147	19·0526	7·1335
314	98596	30959144	17·7200	6·7969	364	132496	48228544	19·0788	7·1400
315	99225	31255875	17·7482	6·8041	365	133225	48627125	19·1050	7·1466
316	99856	31554496	17·7764	6·8113	366	133956	49027896	19·1311	7·1531
317	100489	31855013	17·8045	6·8185	367	134689	49430863	19·1572	7·1596
318	101124	32157432	17·8326	6·8256	368	135424	49836032	19·1833	7·1661
319	101761	32461759	17·8606	6·8328	369	136161	50243409	19·2094	7·1726
320	102400	32768000	17·8885	6·8399	370	136900	50653000	19·2354	7·1791
321	103041	33076161	17·9165	6·8470	371	137641	51064811	19·2614	7·1855
322	103684	33386248	17·9444	6·8541	372	138384	51478848	19·2873	7·1920
323	104329	33698267	17·9722	6·8612	373	139129	51895117	19·3132	7·1984
324	104976	34012224	18·0000	6·8683	374	139876	52313624	19·3391	7·2048
325	105625	34328125	18·0278	6·8753	375	140625	52734375	19·3649	7·2112
326	106276	34645976	18·0555	6·8824	376	141376	53157376	19·3907	7·2177
327	106929	34965783	18·0831	6·8894	377	142129	53582633	19·4165	7·2240
328	107584	35287552	18·1108	6·8964	378	142884	54010152	19·4422	7·2304
329	108241	35611289	18·1384	6·9034	379	143641	54439939	19·4679	7·2368
330	108900	35937000	18·1659	6·9104	380	144400	54872000	19·4936	7·2432
331	109561	36264691	18·1934	6·9174	381	145161	55306341	19·5192	7·2495
332	110224	36594368	18·2209	6·9244	382	145924	55742968	19·5448	7·2558
333	110889	36926037	18·2483	6·9313	383	146689	56181887	19·5704	7·2622
334	111556	37259704	18·2757	6·9382	384	147456	56623104	19·5959	7·2685
335	112225	37595375	18·3030	6·9451	385	148225	57066625	19·6214	7·2748
336	112896	37933056	18·3303	6·9521	386	148996	57512456	19·6469	7·2811
337	113569	38272753	18·3576	6·9589	387	149769	57960603	19·6723	7·2874
338	114244	38614472	18·3848	6·9658	388	150544	58411072	19·6977	7·2936
339	114921	38958219	18·4120	6·9727	389	151321	58863869	19·7231	7·2999
340	115600	39304000	18·4391	6·9795	390	152100	59319000	19·7484	7·3061
341	116281	39651821	18·4662	6·9864	391	152881	59776471	19·7737	7·3124
342	116964	40001688	18·4932	6·9932	392	153664	60236288	19·7990	7·3186
343	117649	40353607	18·5203	7·0000	393	154449	60698457	19·8242	7·3248
344	118336	40707584	18·5472	7·0068	394	155236	61162984	19·8494	7·3310
345	119025	41063625	18·5742	7·0136	395	156025	61629875	19·8746	7·3372
346	119716	41421736	18·6011	7·0203	396	156816	62099136	19·8997	7·3434
347	120409	41781923	18·6279	7·0271	397	157609	62570773	19·9249	7·3496
348	121104	42144192	18·6548	7·0338	398	158404	63044792	19·9499	7·3558
349	121801	42508549	18·6815	7·0406	399	159201	63521199	19·9750	7·3619

SQUARES, CUBES, AND ROOTS—(*Continued*).

n	n^2	n^3	$\sqrt{n}$	$\sqrt[3]{n}$	n	n^2	n^3	$\sqrt{n}$	$\sqrt[3]{n}$
400	160000	64000000	20·0000	7·3681	450	202500	91125000	21·2132	7·6631
401	160801	64481201	20·0250	7·3742	451	203401	91733851	21·2368	7·6688
402	161604	64964808	20·0499	7·3803	452	204304	92345408	21·2603	7·6744
403	162409	65450827	20·0749	7·3864	453	205209	92959677	21·2838	7·6801
404	163216	65939264	20·0998	7·3925	454	206116	93576664	21·3073	7·6857
405	164025	66430125	20·1246	7·3986	455	207025	94196375	21·3307	7·6914
406	164836	66923416	20·1494	7·4047	456	207936	94818816	21·3542	7·6970
407	165649	67419143	20·1742	7·4108	457	208849	95443993	21·3776	7·7026
408	166464	67917312	20·1990	7·4169	458	209764	96071912	21·4009	7·7082
409	167281	68417929	20·2237	7·4229	459	210681	96702579	21·4243	7·7138
410	168100	68921000	20·2485	7·4290	460	211600	97336000	21·4476	7·7194
411	168921	69426531	20·2731	7·4350	461	212521	97972181	21·4709	7·7250
412	169744	69934528	20·2978	7·4410	462	213444	98611128	21·4942	7·7306
413	170569	70444997	20·3224	7·4470	463	214369	99252847	21·5174	7·7362
414	171396	70957944	20·3470	7·4530	464	215296	99897344	21·5407	7·7418
415	172225	71473375	20·3715	7·4590	465	216225	100544625	21·5639	7·7473
416	173056	71991296	20·3961	7·4650	466	217156	101194696	21·5870	7·7529
417	173889	72511713	20·4206	7·4710	467	218089	101847563	21·6102	7·7584
418	174724	73034632	20·4450	7·4770	468	219024	102503232	21·6333	7·7639
419	175561	73560059	20·4695	7·4829	469	219961	103161709	21·6564	7·7695
420	176400	74088000	20·4939	7·4889	470	220900	103823000	21·6795	7·7750
421	177241	74618461	20·5183	7·4948	471	221841	104487111	21·7025	7·7805
422	178084	75151448	20·5426	7·5007	472	222784	105154048	21·7256	7·7860
423	178929	75686967	20·5670	7·5067	473	223729	105823817	21·7486	7·7915
424	179776	76225024	20·5913	7·5126	474	224676	106496424	21·7715	7·7970
425	180625	76765625	20·6155	7·5185	475	225625	107171875	21·7945	7·8025
426	181476	77308776	20·6398	7·5244	476	226576	107850176	21·8174	7·8079
427	182329	77854483	20·6640	7·5302	477	227529	108531333	21·8403	7·8134
428	183184	78402752	20·6882	7·5361	478	228484	109215352	21·8632	7·8188
429	184041	78953589	20·7123	7·5420	479	229441	109902239	21·8861	7·8243
430	184900	79507000	20·7364	7·5478	480	230400	110592000	21·9089	7·8297
431	185761	80062991	20·7605	7·5537	481	231361	111284641	21·9317	7·8352
432	186624	80621568	20·7846	7·5595	482	232324	111980168	21·9545	7·8406
433	187489	81182737	20·8087	7·5654	483	233289	112678587	21·9773	7·8460
434	188356	81746504	20·8327	7·5712	484	234256	113379904	22·0000	7·8514
435	189225	82312875	20·8567	7·5770	485	235225	114084125	22·0227	7·8568
436	190096	82881856	20·8806	7·5828	486	236196	114791256	22·0454	7·8622
437	190969	83453453	20·9045	7·5886	487	237169	115501303	22·0681	7·8676
438	191844	84027672	20·9284	7·5944	488	238144	116214272	22·0907	7·8730
439	192721	84604519	20·9523	7·6001	489	239121	116930169	22·1133	7·8784
440	193600	85184000	20·9762	7·6059	490	240100	117649000	22·1359	7·8837
441	194481	85766121	21·0000	7·6117	491	241081	118370771	22·1585	7·8891
442	195364	86350888	21·0238	7·6174	492	242064	119095488	22·1811	7·8944
443	196249	86938307	21·0476	7·6232	493	243049	119823157	22·2036	7·8998
444	197136	87528384	21·0713	7·6289	494	244036	120553784	22·2261	7·9051
445	198025	88121125	21·0950	7·6346	495	245025	121287375	22·2486	7·9105
446	198916	88716536	21·1187	7·6403	496	246016	122023936	22·2711	7·9158
447	199809	89314623	21·1424	7·6460	497	247009	122763473	22·2935	7·9211
448	200704	89915392	21·1660	7·6517	498	248004	123505992	22·3159	7·9264
449	201601	90518849	21·1896	7·6574	499	249001	124251499	22·3383	7·9317

PRINCIPAL ABBREVIATIONS.

A.C. *or* a.c. alternating current.
a.m. . ante meridiem.
amp(s). . ampere(s).
amp.-hr. . ampere-hour.
antilog. . anti-logarithm.
approx. . approximately.
armtr. . armature.
avoidps. . avoirdupois.

B. . . flux density in iron.
B.E.A.M.A. British Electrical and Allied Manufacturers' Association.
B.E.S.A. . British Engineering Standards Association.
B.O.T. . Board of Trade.
B.T.H. . British Thomson Houston.
B.T.U. . Board of Trade Unit.
B.Th.U. . British Thermal Unit.

c. . . cubic.
°C. . . degree Centigrade.
c.c. . . continuous current
cc. . . cubic centimetre.
cdl. . . candle.
cdl.-ft. . . candle-foot.
Cent. . Centigrade.
cf. . . compare with.
c.ft. . . cubic foot.
C.G.S. . Centimetre - gramme - second.
ch. . . charge.
circt. . circuit.
circumf. . circumference.
cm. . . centimetre.
col(s). . column(s).
condr(s). . conductor(s).
c.p. . . candle-power.
C.T.S. . Cab-Tyre Sheathed.
cu. *or* cub. cubic.

D.C. *or* d.c. direct current.
diam. . diameter.
disch. . discharge.
efficy. . efficiency.
e.g. . . for example.
e.h.t. . extra high tension.
E.M.F. *or* e.m.f. . electromotive force.
E.P.S. . Electric Power Storage.
E.S.C. . Engineering Standards Committee (now British Engineering Standards Association).

°F. . . degree Fahrenheit.
Fahr. . Fahrenheit.

G.E.C. . General Electric Co.
gr(s). . grain(s).
grm(s). . gramme(s).
H. . . magnetising field strength.
H.O. . Home Office.
H.P. *or* h.p. horse-power.
h.t. . . high tension.
I.E.E. . Institution of Electrical Engineers.
incan. . incandescent.
Kg. *or* kilos. kilogramme(s).
kw(s). . kilowatt(s).
L.C.C. . London County Council.
log. . . logarithm.
l.t. . . low tension.
max. . maximum.
m.h.c.p. . mean horizontal candle-power.
m.h.-s. . mean hemispherical.
m.h.-s.c.p. mean hemispherical candle-power.
mil . . one-thousandth of 1 inch.
min. . minute *or* minimum.
ml(s). . mile(s).
M.M.F. *or* m.m.f. . magneto-motive force.
m.s.c.p. . mean spherical candle-power.
N. . . North.
neg. . . negative.
P.D. *or* p.d. potential difference.
p.f. . . power factor.
ph. . . phase.
p.m. . post meridiem *or* per minute.
pos. . . positive.
pr(s). . pair(s).
res. *or* resist. resistance.
rev(s). . revolution(s).
R.M.S. *or* r.m.s. . root mean square.
R.P.M. *or* r.p.m. . revolutions per minute.
S. . . South.
satd. . saturated.
sectnl. . sectional.
slca.-Hg. . silica-mercury.
sp.gr. . specific gravity.
st'd'rd. . standard.
S.W.G. . Standard Wire Gauge.
temp(r). . temperature.
V *or* v. . volt.
W. *or* w. . watt(s).

DIARY

AND

MEMORANDA

FOR

1921

1st—SATURDAY

2nd—SUNDAY

3rd—MONDAY

4th—TUESDAY

5th—WEDNESDAY

6th—THURSDAY

7th—FRIDAY

8th—SATURDAY

9th—SUNDAY

10th—MONDAY

11th—TUESDAY

12th—WEDNESDAY

13th—THURSDAY

14th—FRIDAY

15th—SATURDAY

16th—SUNDAY

17th—Monday

18th—Tuesday

19th—Wednesday

20th—Thursday

21st—Friday

22nd—Saturday

23rd—Sunday

24th—MONDAY

25th—TUESDAY

26th—WEDNESDAY

27th—THURSDAY

28th—FRIDAY

29th—SATURDAY

30th—SUNDAY

31st—MONDAY

1st FEBRUARY—TUESDAY

2nd—WEDNESDAY

3rd—THURSDAY

4th—FRIDAY

5th—SATURDAY

6th—SUNDAY

7th—Monday

8th—Tuesday

9th—Wednesday

10th—Thursday

11th—Friday

12th—Saturday

13th—Sunday

14th—Monday

15th—Tuesday

16th—Wednesday

17th—Thursday

18th—Friday

19th—Saturday

20th—Sunday

21st—Monday

22nd—Tuesday

23rd—Wednesday

24th—Thursday

25th—Friday

26th—Saturday

27th—Sunday

28th—MONDAY

1st MARCH—TUESDAY

2nd—WEDNESDAY

3rd—THURSDAY

4th—FRIDAY

5th—SATURDAY

6th—SUNDAY

7th—Monday

8th—Tuesday

9th—Wednesday

10th—Thursday

11th—Friday

12th—Saturday

13th—Sunday

14th—Monday

15th—Tuesday

16th—Wednesday

17th—Thursday

18th—Friday

19th—Saturday

20th—Sunday

21st—Monday

22nd—Tuesday

23rd—Wednesday

24th—Thursday

25th—Friday—Good Friday

26th—Saturday

27th—Sunday

28th—MONDAY—Bank Holiday

29th—TUESDAY

30th—WEDNESDAY

31st—THURSDAY

1st APRIL—FRIDAY

2nd—SATURDAY

3rd—SUNDAY

4th—MONDAY

5th—TUESDAY

6th—WEDNESDAY

7th—THURSDAY

8th—FRIDAY

9th—SATURDAY

10th—SUNDAY

11th—Monday

12th—Tuesday

13th—Wednesday

14th—Thursday

15th—Friday

16th—Saturday

17th—Sunday

18th—Monday

19th—Tuesday

20th—Wednesday

21st—Thursday

22nd—Friday

23rd—Saturday

24th—Sunday

25th—MONDAY

26th—TUESDAY

27th—WEDNESDAY

28th—THURSDAY

29th—FRIDAY

30th—SATURDAY

1st MAY—SUNDAY

2nd—Monday

3rd—Tuesday

4th—Wednesday

5th—Thursday

6th—Friday

7th—Saturday

8th—Sunday

9th—Monday

10th—Tuesday

11th—Wednesday

12th—Thursday

13th—Friday

14th—Saturday

15th—Sunday

16th—MONDAY—Bank Holiday

17th—TUESDAY

18th—WEDNESDAY

19th—THURSDAY

20th—FRIDAY

21st—SATURDAY

22nd—SUNDAY

23rd—Monday

24th—Tuesday

25th—Wednesday

26th—Thursday

27th—Friday

28th—Saturday

29th—Sunday

30th—Monday

31st—Tuesday

1st JUNE—Wednesday

2nd—Thursday

3rd—Friday

4th—Saturday

5th—Sunday

6th—MONDAY

7th—TUESDAY

8th—WEDNESDAY

9th—THURSDAY

10th—FRIDAY

11th—SATURDAY

12th—SUNDAY

13th—MONDAY

14th—TUESDAY

15th—WEDNESDAY

16th—THURSDAY

17th—FRIDAY

18th—SATURDAY

19th—SUNDAY

20th—Monday

21st—Tuesday

22nd—Wednesday

23rd—Thursday

24th—Friday

25th—Saturday

26th—Sunday

27th—MONDAY

28th—TUESDAY

29th—WEDNESDAY

30th—THURSDAY

1st JULY—FRIDAY

2nd—SATURDAY

3rd—SUNDAY

4th—MONDAY

5th—TUESDAY

6th—WEDNESDAY

7th—THURSDAY

8th—FRIDAY

9th—SATURDAY

10th—SUNDAY

11th—MONDAY

12th—TUESDAY

13th—WEDNESDAY

14th—THURSDAY

15th—FRIDAY

16th—SATURDAY

17th—SUNDAY

18th—MONDAY

19th—TUESDAY

20th—WEDNESDAY

21st—THURSDAY

22nd—FRIDAY

23rd—SATURDAY

24th—SUNDAY

25th—MONDAY

26th—TUESDAY

27th—WEDNESDAY

28th—THURSDAY

29th—FRIDAY

30th—SATURDAY

31st—SUNDAY

1st **AUGUST**—MONDAY—Bank Holiday

2nd—TUESDAY

3rd—WEDNESDAY

4th—THURSDAY

5th—FRIDAY

6th—SATURDAY

7th—SUNDAY

8th—MONDAY

9th—TUESDAY

10th—WEDNESDAY

11th—THURSDAY

12th—FRIDAY

13th—SATURDAY

14th—SUNDAY

15th—MONDAY

16th—TUESDAY

17th—WEDNESDAY

18th—THURSDAY

19th—FRIDAY

20th—SATURDAY

21st—SUNDAY

22nd—MONDAY

23rd—TUESDAY

24th—WEDNESDAY

25th—THURSDAY

26th—FRIDAY

27th—SATURDAY

28th—SUNDAY

29th—MONDAY

30th—TUESDAY

31st—WEDNESDAY

1st SEPTEMBER—THURSDAY

2nd—FRIDAY

3rd—SATURDAY

4th—SUNDAY

5th—MONDAY

6th—TUESDAY

7th—WEDNESDAY

8th—THURSDAY

9th—FRIDAY

10th—SATURDAY

11th—SUNDAY

12th—Monday

13th—Tuesday

14th—Wednesday

15th—Thursday

16th—Friday

17th—Saturday

18th—Sunday

19th—Monday

20th—Tuesday

21st—Wednesday

22nd—Thursday

23rd—Friday

24th—Saturday

25th—Sunday

26th—MONDAY

27th—TUESDAY

28th—WEDNESDAY

29th—THURSDAY

30th—FRIDAY

1st OCTOBER—SATURDAY

2nd—SUNDAY

3rd—Monday

4th—Tuesday

5th—Wednesday

6th—Thursday

7th—Friday

8th—Saturday

9th—Sunday

10th—MONDAY

11th—TUESDAY

12th—WEDNESDAY

13th—THURSDAY

14th—FRIDAY

15th—SATURDAY

16th—SUNDAY

17th—MONDAY

18th—TUESDAY

19th—WEDNESDAY

20th—THURSDAY

21st—FRIDAY

22nd—SATURDAY

23rd—SUNDAY

24th—Monday

25th—Tuesday

26th—Wednesday

27th—Thursday

28th—Friday

29th—Saturday

30th—Sunday

31st—MONDAY

1st NOVEMBER—TUESDAY

2nd—WEDNESDAY

3rd—THURSDAY

4th—FRIDAY

5th—SATURDAY

6th—SUNDAY

7th—MONDAY

8th—TUESDAY

9th—WEDNESDAY

10th—THURSDAY

11th—FRIDAY

12th—SATURDAY

13th—SUNDAY

14th—Monday

15th—Tuesday

16th—Wednesday

17th—Thursday

18th—Friday

19th—Saturday

20th—Sunday

21st—MONDAY

22nd—TUESDAY

23rd—WEDNESDAY

24th—THURSDAY

25th—FRIDAY

26th—SATURDAY

27th—SUNDAY

28th—Monday

29th—Tuesday

30th—Wednesday

1st DECEMBER—Thursday

2nd—Friday

3rd—Saturday

4th—Sunday

5th—Monday

6th—Tuesday

7th—Wednesday

8th—Thursday

9th—Friday

10th—Saturday

11th—Sunday

12th—Monday

13th—Tuesday

14th—Wednesday

15th—Thursday

16th—Friday

17th—Saturday

18th—Sunday

19th—Monday

20th—Tuesday

21st—Wednesday

22nd—Thursday

23rd—Friday

24th—Saturday

25th—Sunday—Christmas Day

26th—MONDAY—Bank Holiday

27th—TUESDAY

28th—WEDNESDAY

29th—THURSDAY

30th—FRIDAY

31st—SATURDAY

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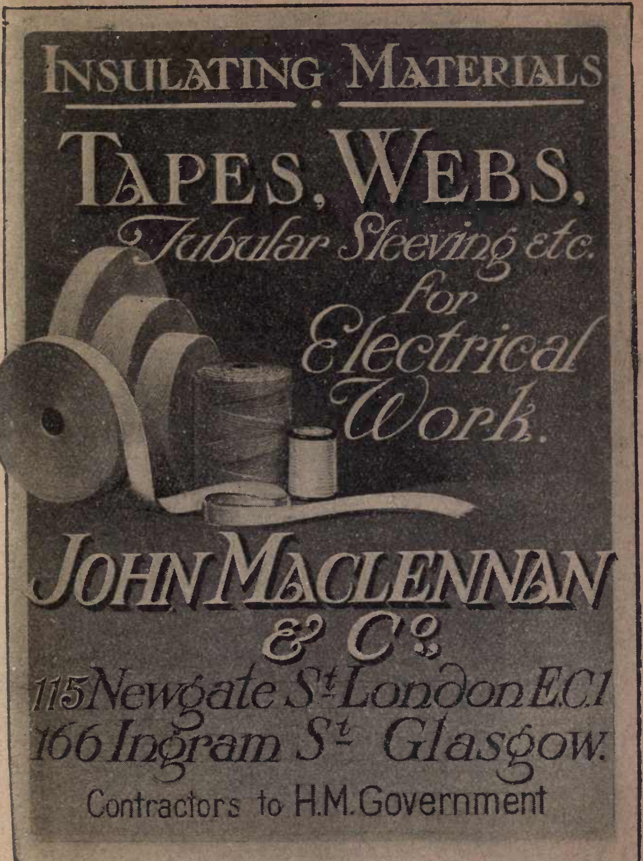
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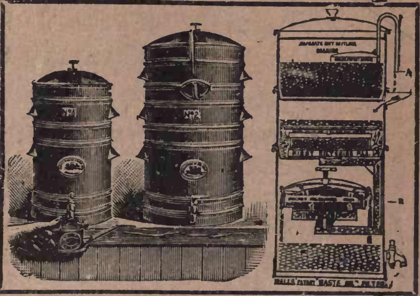

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